DOCUMENT RESUME

ED 291 565 SE 048 897

AUTHOR	Lord, Douglas R.
TITLE	Spacelab: An International Success Story.
INSTITUTION	National Aeronautics and Space Administration, Washington, DC. Scientific and Technical Information Branch.
REPORT NO	NASA-SP-487
PUB DATE	86
NOTE	558p.; Some drawings and photographs may not reproduce well.
AVAILABLE FROM	Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.
PUB TYPE	Historical Materials (060) -- Reports - Descriptive (141) -- Books (010)
EDRS PRICE	MF02/PC23 Plus Postage.
DESCRIPTORS	*College Science; Higher Education; History Instruction; History Textbooks; *International Cooperation; International Programs; International Relations; Science and Society; Science Education; Science Equipment; Science Experiments; *Science History; *Secondary School Science; *Space Exploration; *Space Sciences
IDENTIFIERS	European Space Agency; National Aeronautics and Space Administration; *Spacelab

ABSTRACT

The Spacelab program was a unique endeavor. For the first time in the history of the United States space effort, the design and development of a major element of a manned space vehicle was entrusted to a foreign agency and to a group of countries which had never before built such a system. This book tells of this cooperative effort between the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) from the program's inception until the delivery of hardware to the United States. This chronological history of the Spacelab project includes chapters on "Building an International Agreement, 1969-1973"; "Birth of a Concept, 1960-1973"; "Getting Under Way, 1973-1974"; "Solidifying the Requirements, 1973-1976"; "Planning for Spacelab Use, 1973-1977"; "Reviews, Reviews, Reviews, 1975-1978"; "At Last--Hardware!, 1976-1979"; "Off the Mainstream, 1974-1984"; "Integration and Acceptance, 1978-1982"; Readiness for Flight, 1979-1983"; "At Long Last--Spacelab Flies!, 1983-1985"; and "Lessons Learned." Appendices include "Memorandum of Understanding"; "Joint Programme Plan"; "Programme Requirements"; Key Program Participants"; and an extensive source list. This book, and the original documents it represents, constitutes basic historical source material for the study of the U.S. manned spaceflight program and for Spacelab in particular. (CW)

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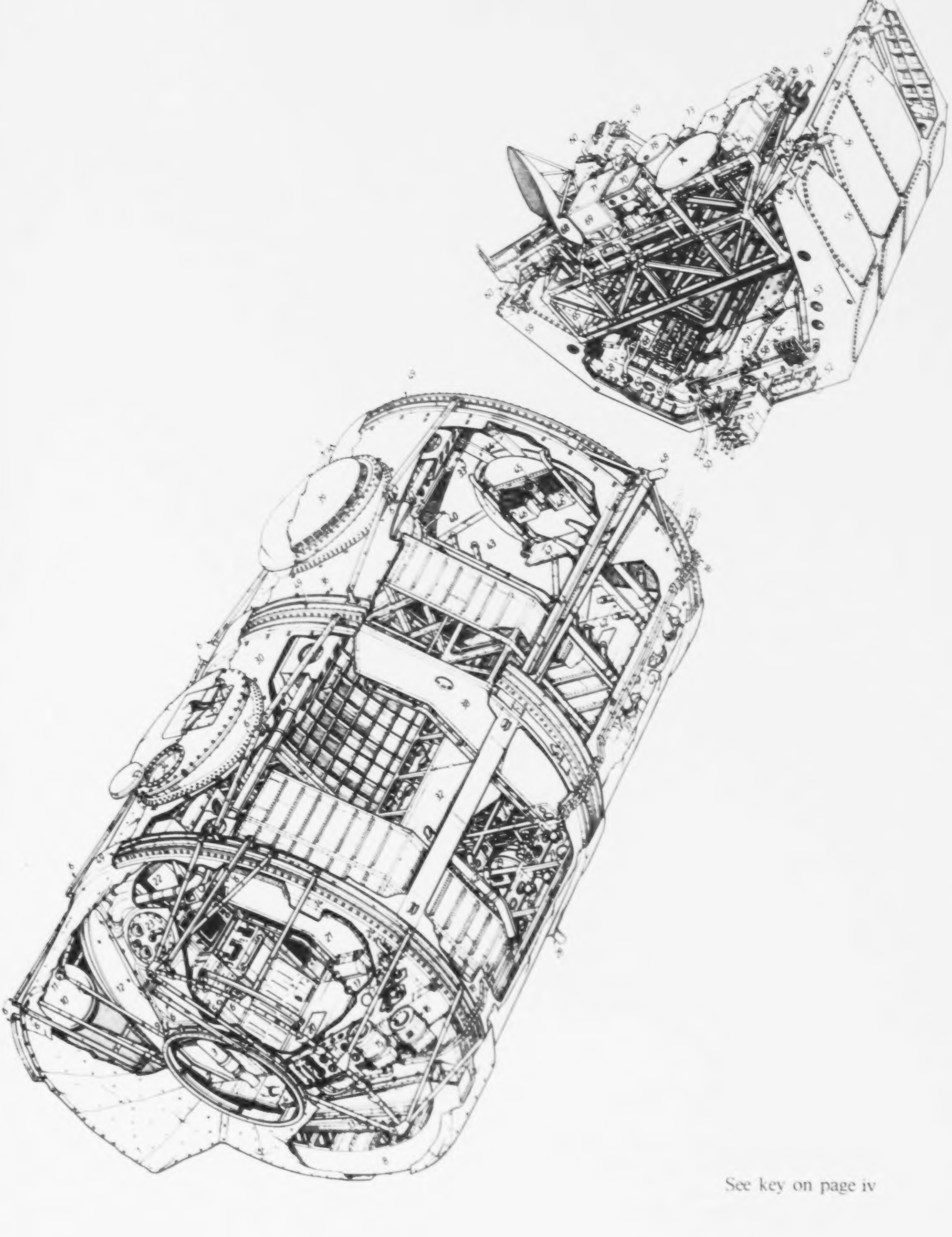
SPACELAB

AN INTERNATIONAL SUCCESS STORY

Douglas R. Lord

SE048897

NASA Scientific and Technical Information Division 1987
National Aeronautics and Space Administration
Washington, DC



See key on page iv

Frontispiece Key

MODULE

1 Insulation blanket
2 Close-outs (skin/racks)
3 Cabin air ducting (from sub-floor)
4 RAAB
5 High Data-rate recorder
6 Handrails
7 Water/Freon heat exchanger
8 Utility tray
9 Gaseous nitrogen supply
10 Gaseous nitrogen tank
11 Temperature transducer
12 Forward end-cone
13 Module/Orbiter lower feed-through plates (two)
14 Insulation blanket supports
15 Freon pump
16 Water pump
17 Lithium Hydroxide cartridge stowage
18 Freon lines
19 Control-centre rack
20 Debris traps
21 Workbench rack
22 Stowage container (lowers for access)
23 Upper module/Orbiter feed through plate
24 Gaseous nitrogen fill-valve bracket
25 Gaseous nitrogen reducing valves (two-stage)
26 Position for double rack
27 Position for single rack
28 Keel fitting
29 Sub-floor
30 Aluminum alloy module shell
31 Electrical connectors for rack
32 Floor of aluminum-skinned honeycomb sandwich (centre panel fixed, outer panels hinge up for access)
33 Overhead duct channels
34 Viewport
35 NASA high-quality window
36 Fasteners for insulation blanket
37 Rack fire-suppression system
38 Double rack
39 Experiment airlock
40 Airlock controls
41 Overhead lights
42 Avionics cooling-air ducts
43 Aft end-cone
44 Radial support structure
45 Fire extinguisher (Halon)
46 Portable oxygen equipment
47 Foot restraint
48 Module/Orbiter pickups (four)
49 Module-segments joints, incorporating seals

PALLET

50 Freon lines from Module
51 Pallet interface
52 Cable ducts
53 Cold plates
54 Inner skin-panels
55 Outer skin-panels
56 Pallet/Orbiter primary pickup
57 Pallet/Orbiter stabiliser pickup
58 Connector supports
59 Pallet hard-points
60 Handrails
61 Support systems Remote Acquisition Unit (RAU)
62 Experiment RAU (several)
63 Experiment power distribution box
64 Pallet/bridge supports
65 Experiment-supporting bridge
66 Electrical junction box
67 Integrally-machined aluminum-alloy ribs

EXPERIMENTS*

68 Synthetic aperture radar
69 Solar spectrum
70 X-ray astronomy
71 Solar constant
72 Charged-particle beam
73 Advanced biostack
74 Isotopic stack
75 Micro-organisms
76 Lyman Alpha
77 Waves
78 Low energy electron-flux

*Representative Experiments

● *Flight Magazine 1982*

Library of Congress Cataloging-in-Publication Data

Lord, Douglas R.
Spacelab, an international success story.

(NASA SP ; 487)
Biliography: p.
1. Spacelab project. I. Title. II. Title: Spacelab.
III. Series.
TL797.L67 1986 629.44'5 86-17979

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

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Foreword

I had the good fortune and awesome responsibility of running NASA in the years 1971-1977 when the Space Shuttle and Spacelab were in their crucial formative years and when most of the events in this book were taking place.

The story of the Spacelab development program is a fascinating but somewhat neglected chapter in the history of the United States space program. I am delighted that this book will help to fill that gap.

Spacelab is important to all of us for at least four good reasons. It expanded the Shuttle's ability to conduct science on-orbit manyfold. It provided a marvelous opportunity and example of a large international joint venture involving government, industry, and science with our European allies. The European effort provided the free world with a really versatile laboratory system several years before it would have been possible if the United States had had to fund it on its own. And finally, it provided Europe with the systems development and management experience they needed to move into the exclusive manned space flight arena.

I am delighted that my friend Doug Lord took on the job of writing this history, because no other individual was as centrally involved in the conception and birth of the Spacelab. The results of his efforts are very complete and objective. They show clearly that people, with their intelligence, determination, integrity, failings, and humor, make programs like Spacelab possible. We all can share in Doug's justifiable pride in a job well done.

James C. Fletcher
NASA Administrator

Preface

The Spacelab program has been a unique endeavor. For the first time in the history of the U.S. space effort, the design and development of a major element of a manned space vehicle was entrusted to a foreign agency and to a group of countries which had never before built such a system.

It was my privilege and honor to be the NASA Director of this cooperative effort with the European Space Agency and its 10 participating countries from the program's inception until the first delivery of hardware to the United States. At the beginning, the challenge seemed immense and the problems to be solved, insurmountable. The Spacelab technical concept was not fully defined, nor was the Shuttle carrier vehicle. The management organizations had never before worked together, and such a large number of nations had never cooperated to build a manned space system. We did not know the capabilities and personalities of the people involved. The requirements and use of the Spacelab for science and applications were not understood. There were questions about funding and schedule. Would the U.S. have to provide technology support? Would the European commitment be sustained until successful completion of the program?

At the end of a decade of development, with the successful completion of the Spacelab 1 mission, the unknowns had become knowns, the problems had been solved. The Spacelab had demonstrated in a convincing fashion its ability as a useful tool for space science and technology. And development teams on both sides of the Atlantic felt a great sense of accomplishment and satisfaction. Within 2 more years the Spacelab 3 and Spacelab 2 missions had been completed successfully, and the Spacelab development program was considered to be complete. Europe had demonstrated to the world its ability to be counted in the top echelon of spacefaring groups. To those of us within the program, however, the greatest satisfactions were in meeting individual technical and programmatic challenges and in building international friendships that would last the rest of our lives.

In early 1983, I received a phone call from Jim Harrington, my successor as NASA's Director of the Spacelab program. After reminiscing about our experiences on the program, he asked whether I would consider writing the story of Spacelab from my vantage point within NASA Headquarters. He pointed out that many of the people on the program were being dispersed to other activities and soon the "corporate memory" would be lost. He, and others, felt that the experiences and lessons of this unusual program should not be lost.

My reactions to Jim's proposal were mixed. Certainly I had no training or experience as an historian, but on the other hand, I thought it would be an interesting challenge. After talking to people both within and outside the program and with representatives of the NASA History Office, I agreed to give it a try. The clinching factor to my agreement, however, was that I would not try to prepare a classical history, with exhaustive research, endless footnotes, and the like. It would be, as near as I could develop it, my view of Spacelab's evolution.

Two important modifications were made to that basic approach. As I gathered documents and files from my own and other sources, I also interviewed some 200 of the very special people from within the program who really did the work and made the program a success. Considering the thousands that participated in the program, this was a small sample, but to me it was the most important resource I used. They reminded me of problems, activities, friendships, briefings, trips, agreements, mistakes, decisions, and anecdotes that I had long ago forgotten. To the degree that I could make it so, this story is theirs, not mine.

Another change was made after review of the preliminary drafts of the first few chapters. Although I had included a few personal comments and stories within the text, many of my recollections were not included because they seemed to interrupt the story I was trying to tell and appeared to me to be, in many cases, too self-serving. At the insistence of my longtime NASA associates Bob Lohman and Bill Hamon, who were also my mentors in the preparation of this text, I agreed to add a section to each chapter relating some of the more personal memories of that particular phase of the program. I take full responsibility for these recollections and hope that they will improve understanding of the program and not detract from our more serious accomplishments.

My general approach in telling the Spacelab story is chronological. However, there are times when I break the continuity to complete the discussion of a particular phase of the program. To help the reader follow the text, a chart of the chronology is provided.

For those within the Spacelab Program who, by your skills and dedication, made this story come true, I again express my appreciation for your many contributions. For those who may have the opportunity to participate in a similar effort now or in the future, you have my envy. For those who will never have such an opportunity, I hope this story will give a sense of the reward I experienced in living it and writing it.

Acknowledgments

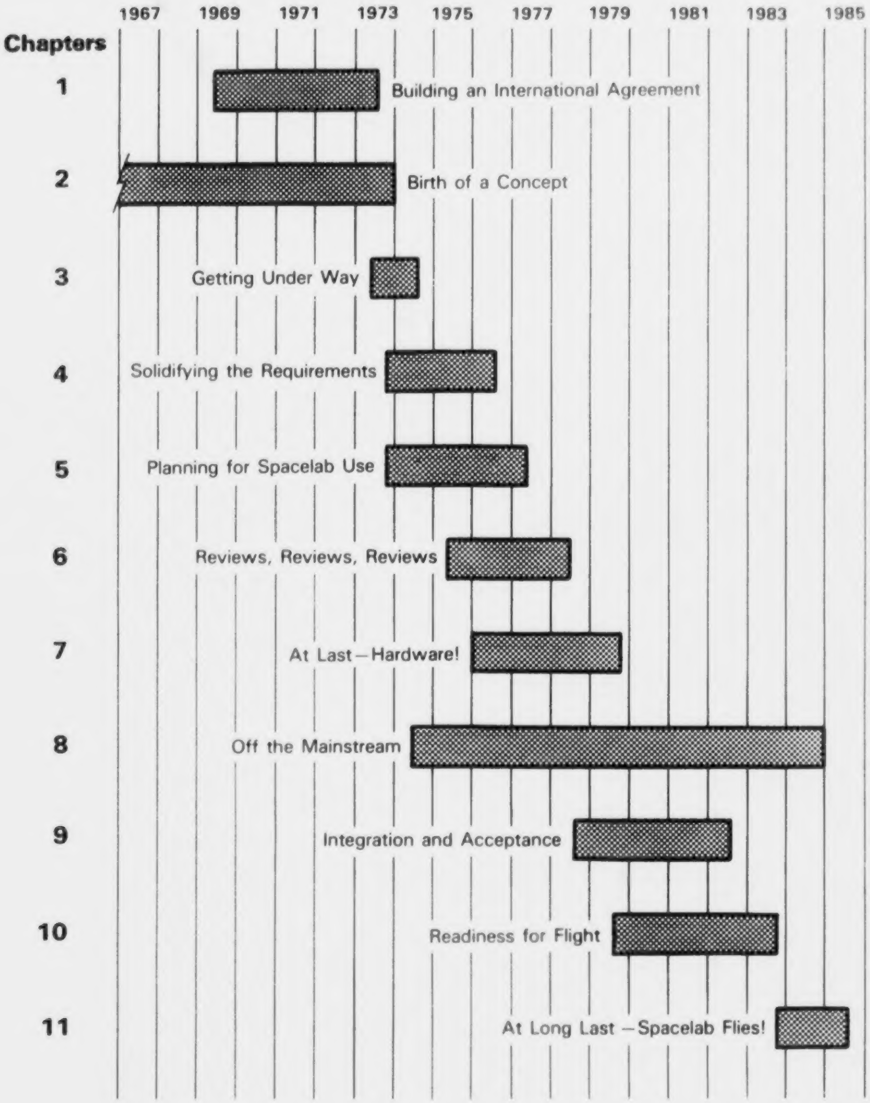
Writing the story of the Spacelab development program turned out to be a much more difficult task than I had envisioned at the start. Without the help of many people, I could not have succeeded. First and most important was the continuing support and help I received from Bob Lohman, the Director of Engineering for the Headquarters Spacelab Program Office throughout the development phase, who provided NASA direction and oversight. Second, I acknowledge Bill Hamon, who negotiated and supervised the contract with NASA for the Science and Applications International Corporation (SAIC) and for whom I served as a consultant in preparing the raw text and in revising subsequent versions.

When I made the round robin of visits to interview participants in the program, I was assisted by Don Bailey at Kennedy Space Center, Dan Blenis at Marshall Space Flight Center, John O'Loughlin at Johnson Space Center, and Dai Shapland at European Space Agency Headquarters. At every government and industry facility I was welcomed, and I was able to interview most of the persons who I felt could contribute to telling this story. These individuals, who are listed among the sources at the end of the book, opened their files and recalled from memory the history told herein. In researching through the files at NASA Headquarters, I was helped repeatedly by Jim Harrington, Al Ryan, Diana Winslow, Ed James, Vickie Thorne, and others.

When it was time to put the story down on paper, Debbie Browning and Debbie Tripp of SAIC provided the typing and word processing that was so necessary for the translation from my terrible penmanship to organized and readable early drafts. With the text finally ready for a technical review, we called on a few of the most experienced participants in the program and they responded willingly. In Europe, Michel Bignier, Chris Reinhold, Robert Mory, Dai Shapland, Gordon Bolton, Heinz Stoewer, Frank Sperling, and Colin Jones provided critique and comments. At NASA Headquarters, Bob Lohman, Al Ryan, and Dick Barnes made many helpful suggestions, as did Sylvia Fries, the NASA Historian. At the NASA centers, the draft was reviewed by Jack Lee, Jerry Richardson, and Ray Tanner at MSFC, John Neilon at KSC, and John O'Loughlin, Jack Heberlig, and Bob Parker at JSC. I have tried to be faithful to the program and considerate of these individuals in revising the text, but I take full responsibility for its final content.

I realize that, by listing so many names in this book and making it so "people oriented," I have taken the risk of overlooking individuals who have contributed in some way to the success of the program. In my opinion, it is more important to recognize as many people as I can, despite that risk. I consider it a privilege to have known and worked directly with most of the people named in this book and am convinced that each one was a valuable contributor.

Chronology of the Text



1 Building an International Agreement 1969–1973

Situation in the United States

In September 1969, a Space Task Group chaired by Vice President Spiro T. Agnew made a series of far-ranging recommendations to President Richard M. Nixon which reflected a balanced manned and unmanned space program. This report was titled "The Post Apollo Space Program Directions for the Future." Its focus was a reusable and economical space transportation system in which the United States should seek "international involvement and participation on a broad basis." Only two months before this report was released, National Aeronautics and Space Administration (NASA) Administrator Dr. Thomas O. Paine had been standing on the deck of an aircraft carrier with President Nixon, awaiting the return of the triumphant *Apollo 11* crew from the Moon. As they discussed the future of the manned spaceflight program, the President made it clear that future efforts should include a significant role for international partnerships.

Seizing on this mandate, NASA Administrator Paine embarked on a series of visits to foreign countries seeking to enlist interest and support in the post-Apollo era of space activities. After visiting several European countries, he traveled to Australia, Japan, and Canada to make the same offer. His visits to London, Paris, Bonn, and Rome during October 13–15, 1969, elicited immediate and enthusiastic response from the Europeans to assess interest within Europe for possible cooperative participation. On October 16 and 17 in Washington, D.C., a review of Space Shuttle design concept studies was attended by 43 foreign participants, giving further evidence of widespread interest in the post-Apollo program.

By the end of 1969, with sufficient support for new program starts of the Space Shuttle and Space Station, NASA created task forces at Headquarters to supervise definition studies of these important and related concepts. Similar task forces were established at Marshall Space Flight Center and the Manned Spacecraft Center (subsequently renamed the Lyndon B. Johnson Space Center) to focus technical support at these key manned space flight centers. Smaller but important support groups were identified at Kennedy Space Center, Langley Research Center, and other NASA field installations. A 1969 forecast of the Space Station development program is shown in figure 1.

On March 7, 1970, President Nixon gave further impetus to the international discussions in a statement on space goals for the 1970s. In this statement, he reiterated the general purposes of the space program for exploration, scientific knowledge, and practical applications. Moreover, he endorsed six specific objectives: to continue to explore the Moon, to explore the planets and the universe, to reduce substantially the cost of space operations, to extend man's capabilities to live and work in space, to hasten and expand the practical applications of space technology, and to encourage greater international cooperation in space.

On March 13, reviews of the Space Shuttle and other studies were conducted by senior management at NASA Headquarters. Forty representatives from 17 countries and regional European organizations participated in this review and gave further indication of the strong support for some kind of European participation in the United States' next manned space activity.

Meanwhile, NASA continued to press toward a Space Station program start. On September 9 and 10, NASA hosted a Space Station Utilization Conference at Ames Research Center. Presentations to a large group of potential Space Station users described the capabilities of the 33-foot-diameter station then in vogue (fig. 2), discussed the features of living and operating on a continuous basis in space, and outlined potential uses in all the applicable scientific and technological disciplines. Special tours of the full-scale mockups then available at North American Rockwell (Seal Beach, California) and McDonnell Douglas Astronautics (Huntington Beach, California) were scheduled in conjunction with the conference. One of the most interesting features of the conference was the first presentation of a Space Station utilization policy by NASA Associate Administrator Dr. Homer E. Newell. This draft policy was the first attempt to delineate how such a permanent facility in space might be shared by potential users and was the subject of considerable debate.

During this time, discussions with European delegations about a possible cooperative effort were generating considerable interest. To clarify the planning guidelines, Acting Administrator Dr. George M. Low issued a memo to key NASA officials on November 2, which stated policies and actions in support of international cooperation in the post-Apollo program. He emphasized that the underlying purpose of the talks was to broaden the program's base of support and to share the costs as well as the benefits. Among the stated principles were no exchange of funds, final direction of the program by NASA but a recognized management role for participating countries, and access to program technology. Finally, he emphasized the need for time and information exchange to facilitate decision making by the foreign nations and stressed the need for a broad partnership of NASA line and staff offices with the full support of program and project personnel. His strong endorsement of

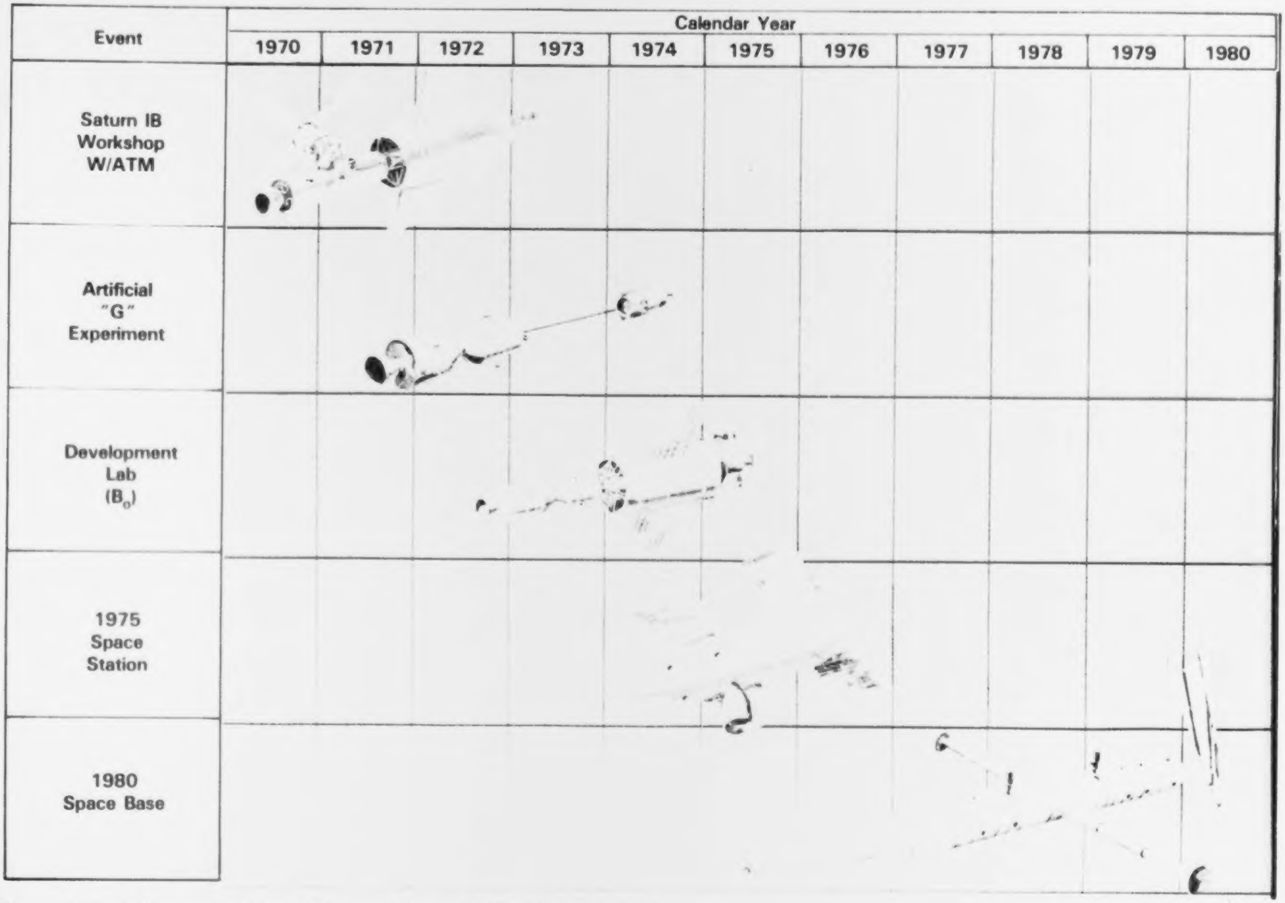

Event
Calendar Year
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
Saturn IB Workshop W/ATM
Artificial "G" Experiment
Development Lab (B_0)
1975 Space Station
1980 Space Base

Figure 1. Early forecast (1969) of the evolution of the NASA Space Station.

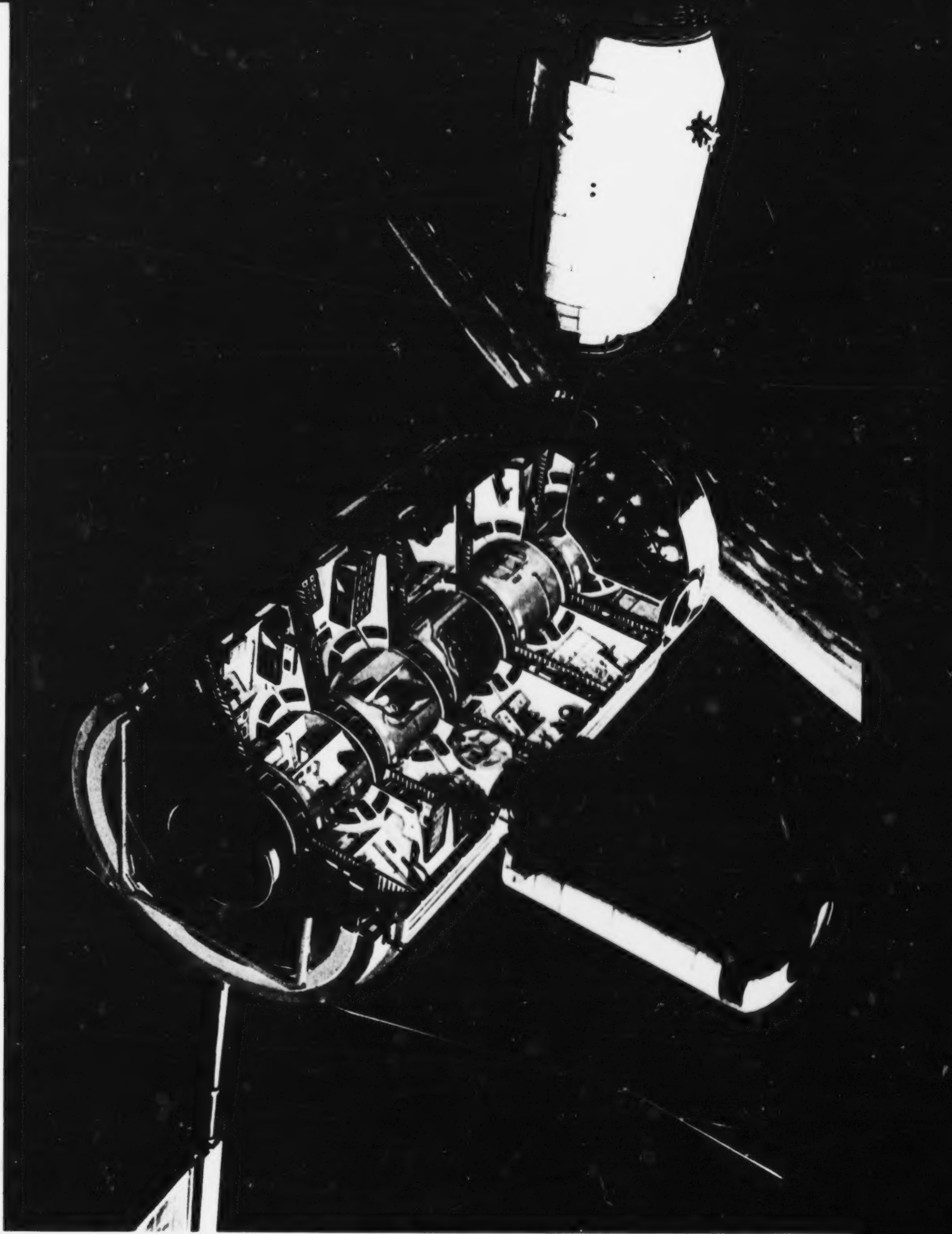


Figure 2. The McDonnell Douglas concept for a 33-foot-diameter Space Station with an attached experiment module and resupply module in the process of docking.

these efforts to produce wide and meaningful international participation in the post-Apollo program was a significant factor in subsequent decisions.

During 1971, it became clear that funding priority was swinging toward the Shuttle and away from the Space Station. Studies of Space Station concepts and uses continued, but a new concept, based on short-duration laboratory use of the Shuttle, also grew in popularity. Ames Research Center was operating a converted Convair 990 airplane as an airborne laboratory (figs. 3 and 4), and its success in providing an efficient platform for scientists to make astronomical measurements as well as Earth observations gave impetus to the idea of using the Space Shuttle in a similar fashion. The scientists who had participated in the 990 missions and the Ames program managers made convincing arguments as to how standard support services and laboratory facilities could be used to convert an aircraft cargo bay into a flexible and quickly accessible facility for airborne research. They argued that the features of quick turnaround, short lead times for experiments, quick data return, and a shirt-sleeve environment could be transferred easily to the Space Shuttle. The added advantages of weightlessness, higher altitudes, wide coverage, and limitless vacuum gave further promise to the Shuttle "sortie" mode. Many of the characteristics of the Convair 990 program thus became the bywords of the Shuttle sortie concept.

On September 10, 1971, as Director of the Headquarters Space Station Task Force, I asked Marshall Space Flight Center to begin an inhouse design study of a Sortie Can, a manned system to be carried in the Shuttle cargo bay for the conduct of short-duration missions. I proposed that the Sortie Can might become a NASA inhouse development effort. The request really left open a number of options by tying the projected study effort to completed and ongoing studies, as well as to the Convair 990-type operation. I also referred to the Concept Verification Test program under way at Marshall to demonstrate manned laboratory systems in a breadboard configuration. Later, full sortie mission simulations would be conducted using a partially closed environment and embryonic data transmission systems. These simulations provided valuable experience and input to Spacelab development.

Finally came the long-awaited decision to begin development of the Space Shuttle. On January 5, 1972, President Nixon gave full approval to NASA for development of the so-called stage-and-a-half system. He pointed out that the Shuttle would permit routine access to space, sharply reduce costs, and broaden opportunities for international cooperation in low-cost, multipurpose space missions. NASA's gamble to abandon the two-stage fully reusable concept, thus reducing developmental complexity while accepting the increased operational cost of the limited reusable boosters and expendable fuel tank, had been successful. Even today, supporters can be found for the fully reusable concept (an early version is shown in figure 5), but on balance, most objective observers support NASA's decision. Most meaningful to those in NASA, however, was the fact that a go-ahead of comparable significance to the 1961 Apollo decision had finally been made. The NASA team had been given a new mandate and a new technical challenge.

Shortly afterward, the NASA Associate Administrator for Manned Space

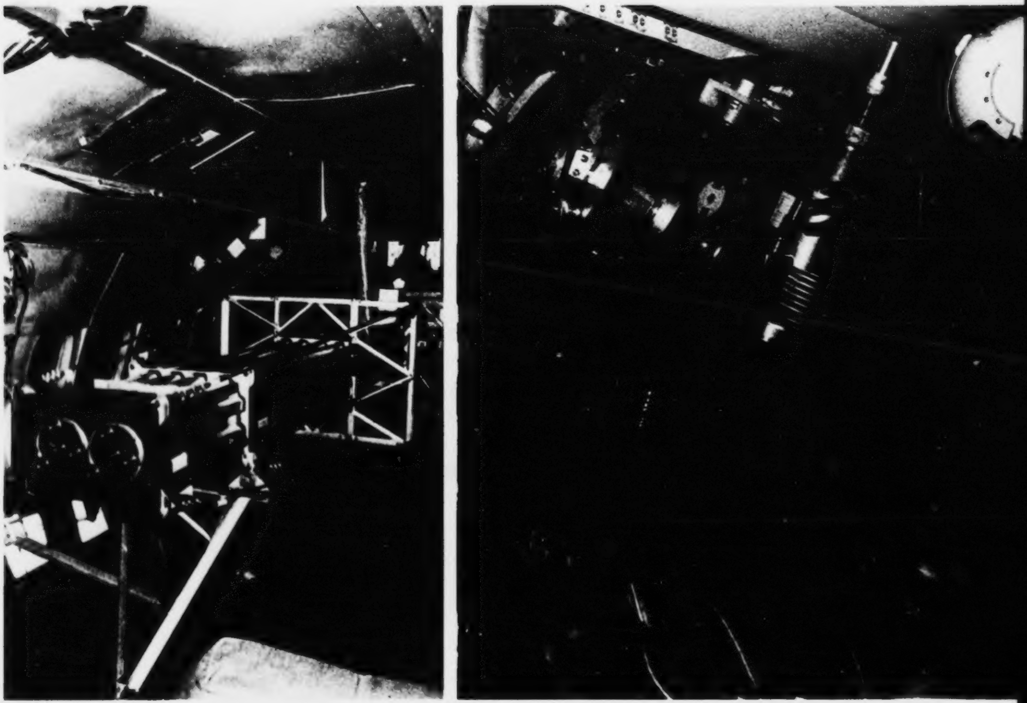


Figure 3. The Ames Airborne Science Laboratory proposed as a model for Shuttle sortie missions. Left: a 30-cm telescope with a two-axis stabilized mirror. Right: an infrared telescope with cryogenically cooled detectors installed in a Learjet.

Flight, Dale Myers, took another look at the Sortie Can and related activities at Marshall Space Flight Center and issued new guidelines on February 16, 1972. He urged Marshall to continue its inhouse definition studies of the Sortie Can (fig. 6). To that end, Marshall had secured a price quote from the local John Blue Manufacturing Company (that makes fertilizer tanks) to build a can to be used as a Sortie Can mockup. However, Myers cautioned against converting the Concept Verification Test effort into a carbon copy of the Sortie Can. Thus, he was still holding out some hope that the CVT could continue to provide low-level technology support for a future Space Station start.

Meanwhile, other potential uses of the Shuttle attracted attention. It was obvious from the start that the Shuttle would be useful as a replacement for expendable launch boosters in placing satellites into low Earth orbits and, in conjunction with upper stages, in sending payloads toward synchronous orbit or deep space. The option for short-duration manned missions, however, would be a new mode of operation. Thus it was necessary to seek the cooperation and support of the scientific

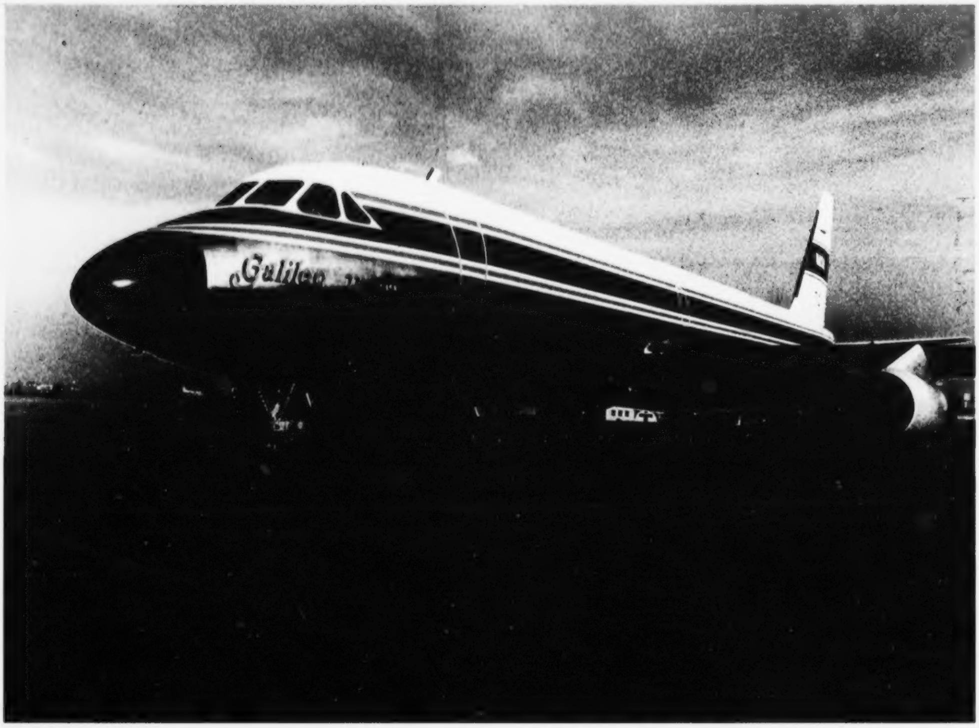


Figure 4. Galileo II, the Convair 990 airplane used by Ames Research Center for the Airborne Science Program in the 1970s.

community to assure that whatever new system was built would be responsive to all user needs and that instruments would be developed which could best profit from this mode of operation.

Dr. John E. Naugle, then NASA Associate Administrator for Space Sciences, deserves a great deal of credit for heading a Space Shuttle Sortie Workshop at the Goddard Space Flight Center from July 31 to August 4, 1972. The principal purpose of this workshop was to inform the entire NASA family of scientists and technologists about the capabilities of the Space Shuttle and the Sortie Laboratory (a more sophisticated name for the Sortie Can) and to get them thinking constructively about the requirements they might impose on these systems and their mission plans. This was a more difficult undertaking than might first appear because many of the potential experimenters were more than content with their unmanned satellites and sounding rockets and had no strong desire to become involved in the new manned systems. They could see nothing but loss of control of their experimental destinies and increased costs to make their instruments man-rated.

Nevertheless, the workshop kickoff team of Deputy Administrator Low, Naugle, and Charles W. Mathews, Associate Administrator for Applications, gave strong endorsement to the new systems and challenged the 200 invitees to show how space experimentation could be conducted at lower cost, with more innovative techniques, and using the best inputs from all potential users. The Ames Convair 990 missions were again used as an example of how to do things faster, simpler, and, most of all, cheaper.

The scientists and technologists at the workshop were assigned to 15 disciplinary working groups and asked to address questions relative to their disciplines' goals and objectives, the way in which achievements could be made through use of the sortie mode, and requirements which their uses would place on the Shuttle and Sortie Lab. Sortie missions were defined as those which employed observations or operations from the Shuttle itself, with short-duration subsatellites of the Shuttle, or with Shuttle-deployed automated spacecraft having unattended lifetimes of less than about half a year. The 15 working groups were as follows:

- Infrared Astronomy
- Optical Astronomy
- X-Ray Astronomy
- Planetary Astronomy
- Solar Physics
- High-Energy Cosmic Ray Physics
- Atmospheric and Space Physics
- Communications and Navigation
- Earth and Ocean Physics Applications
- Earth Resources and Surface Environmental Quality
- Meteorology and Atmospheric Environmental Quality
- Oceanography
- Material Processing and Space Manufacturing
- Space Technology
- Life Sciences

The results of the working groups' deliberations were later published in a set of reports 2 inches thick, replete with ideas for potential use of the sortie mode in every discipline, with suggestions for further research and instrument and technology development, and with thoughts about the role of man to enhance the experimental observations. More important, the participants found themselves caught up in a spirit of cooperation and enthusiasm. They had been challenged, and they responded.

Soon thereafter, NASA recognized the inevitable postponement of its Space Station plans by changing the name of the Space Station Task Force to the Sortie Lab Task Force. It was obvious by November 1972 that the Sortie Lab was becoming a reality (fig. 7) and that the Space Station was to be delayed indefinitely.

Since the Manned Spacecraft Center (Johnson Space Center) was busy with technical management of the Space Shuttle development, it was obvious to NASA management that Marshall Space Flight Center, its largest center, should provide technical management of the Sortie Lab effort. Furthermore, at this time MSFC was developing valuable and pertinent expertise in directing the Skylab program. Although the MSFC team accepted the leadership of the Headquarters Task Force

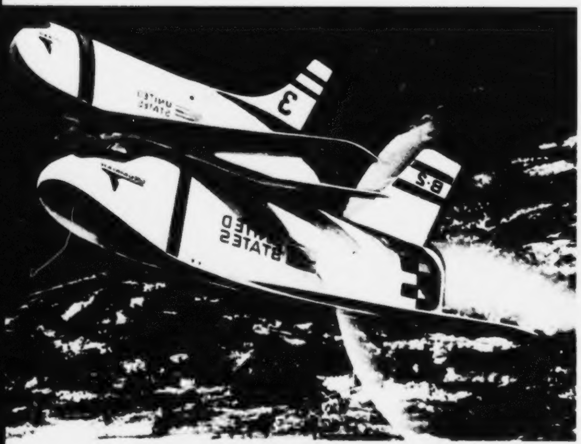


Figure 5. Grumman's early two-stage reusable concept for the Space Shuttle.

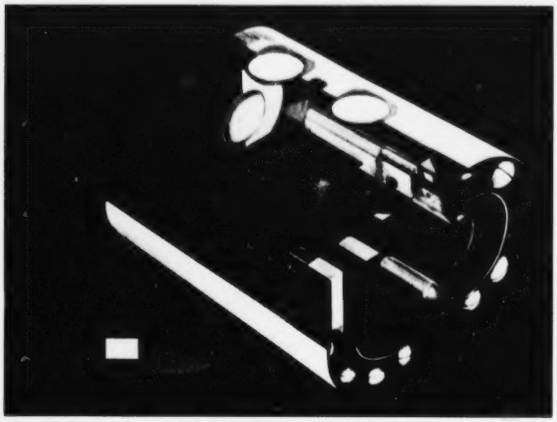


Figure 6. Concept of the Sortie Can developed by the Marshall Space Flight Center Preliminary Design Office.

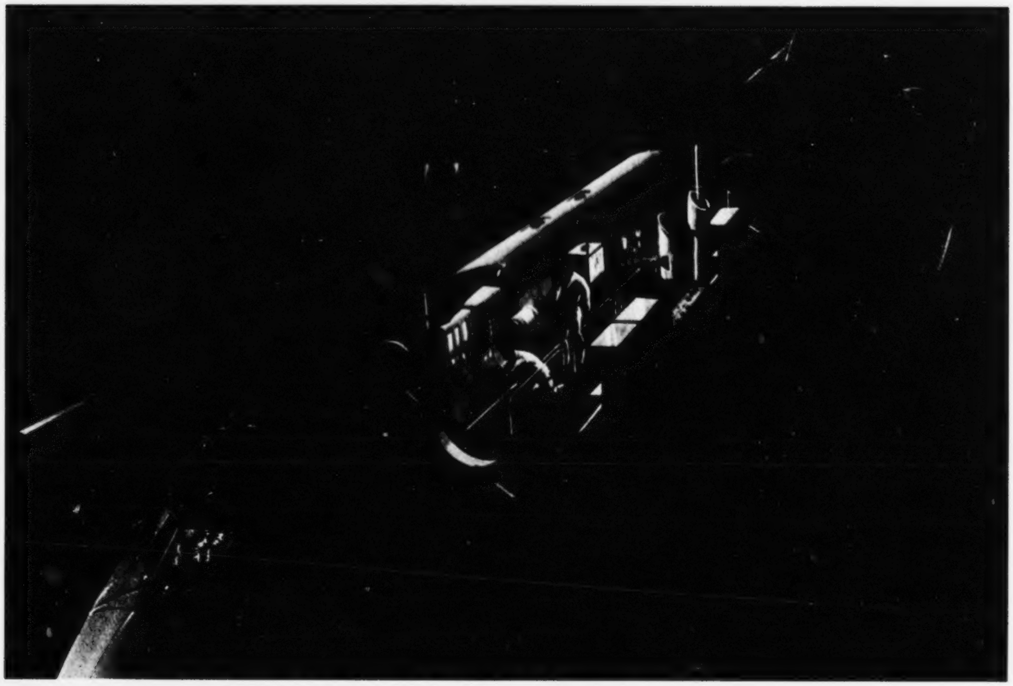


Figure 7. The Sortie Lab concept envisaged by NASA in late 1972.

and recognized its role in obtaining funding and providing managerial oversight to the NASA Sortie Lab effort, the responsibilities of the two organizations in the event of a cooperative program with Europe became a matter for debate. In particular, the MSFC team anticipated that it would provide the principal interface with Europe in the planned development effort. MFSC Director Rocco Petrone had a strong vision that Spacelab would provide a central focus for NASA experiment development and mission management in the Shuttle era. The Headquarters Task Force role was significantly strengthened on December 19, 1972, when Myers issued instructions to MSFC that coordination with the Europeans would be primarily a Headquarters responsibility, at least until the Phase B studies were completed and a firm commitment had been made by the Europeans. He emphasized the very sensitive political, programmatic, and technical issues of the program and the need to move gradually into a strong lead center role for MSFC during the Phase B effort. This was a difficult pill for the MSFC team to swallow and caused some bad feelings for a time, but eventually the relationship between the Headquarters and center teams became very close and cooperative.

The next step in providing better user recommendations for the definition of the Space Shuttle was to broaden the membership of the working groups from the Goddard workshop to include non-NASA users (including European scientists) and to consider all modes of use of the Shuttle. Some of the working groups were combined where appreciable overlap occurred, and the following groups resulted:

Astronomy
Atmospheric and Space Physics
High-Energy Astrophysics
Solar Physics
Life Sciences
Communication and Navigation
Earth Observations
Earth and Ocean Physics
Materials Processing and Space Manufacturing
Space Technology

The expanded working groups reviewed the findings from the Goddard workshop, identified new requirements for the Shuttle and sortie systems, and identified systems and subsystems to be developed in each discipline. They also identified supporting research and technology needs, noted changes in policies or procedures to fully exploit the Shuttle, and prepared cost, schedule, and priority rankings for early missions. These results were published in May 1973.

Another significant development was NASA's creation of an ad hoc organization for Shuttle payload planning. A policy group was chaired by NASA Associate Administrator Homer E. Newell, which consisted of each of the Program Office Associate Administrators plus the directors of the life sciences and international programs. Reporting to the policy group was a steering group chaired by Dr. Naugle, with senior Headquarters and center representatives and a European Space Research Organization (ESRO) representative as members. Working groups, in turn, reported to this steering group. Over the next several years, the Space Shuttle Payload Planning Steering Group became the forum for developing concepts of the Shuttle and related systems. While the meetings often disintegrated into classic gripe sessions with neither side (Shuttle systems or potential users) satisfied with what the other side was doing, the value of the communications far exceeded the drawbacks of these petty differences.

Another formative activity which should be mentioned was the National Academy of Sciences Summer Study at Woods Hole, Massachusetts during July 2-14, 1973. Sponsored by the Academy's Space Sciences Board, this study reviewed the plans for Shuttle utilization in the science disciplines. The Sortie Lab was certainly not the most popular program presented to this group of scientists. With the exception of the life scientists present, most of the attendees felt their resources could be better placed on automated systems in the conventional space science disciplines. Once faced with the fact that a Sortie Lab would probably be provided by a European cooperative effort, they grudgingly conceded that there were some ways in which it could be useful to all disciplines, either in a pressurized module form or with open pallets for mounting instruments externally. Again, however, most of the traditional space experimenters argued strongly for the pallet-only mode so that it was not necessary to pay the performance penalty for carrying the science crew on board. They preferred having the scientists in control on the ground. It was during this time that we also became aware of the significant loss in payload for extending the mission duration. For a 30-day mission, there would be virtually no payload.

At the closing session, the study chairman, Dr. John Findlay, presented a summary to Academy and other officials, including the new NASA Administrator, Dr. James C. Fletcher, and the Director General of ESRO, Dr. Alexander Hocker. The study concluded that the Shuttle, with its large and flexible payload capability, could have a major impact on space science. It also concluded that the sortie mode offered many desirable features for science such as the interaction of man with instruments through the use of Payload Specialists in the Orbiter cabin or in the pressurized module of the Sortie Lab. The study also endorsed long-duration missions, the use of the pallet for conducting remote experiments, and for piggybacking free-flying satellites.

SITUATION IN EUROPE

Prior to any mention by the 1969 Space Task Group of foreign involvement in the Shuttle, Professor H. Bondi, then the ESRO Director General, had met with NASA Administrator Paine and NASA Assistant Administrator for International Affairs, Arnold W. Frutkin. Frutkin recalls how Paine enthusiastically described his ideas for a 100-man Space Station to be resupplied by a Space Shuttle. Bondi, in turn, reacted that such a program was tremendously exciting and that it would be wonderful if the Europeans could participate in some manner. Frutkin, the architect of NASA's very successful international program, recommended that Paine make the same presentation at several key sites in Europe. Paine's visit to Europe in October 1969 ensued. The European response to NASA Administrator Paine's overture was immediate and strong. Specifically, the European Space Conference (ESC), the ministerial group overseeing cooperative Eurpean space activities, authorized and supported a broad-based series of studies and technological efforts to prepare the way for future European participation in NASA's post-Apollo program. The European space organizations then in existence, the European Launcher Development Organization (ELDO) and the European Space Research Organization (ESRO), took the lead in conducting the various study efforts and in carrying out technical discussions with NASA. ELDO was faltering in its ongoing program to develop the Europa expendable launch vehicle, and it aggressively pursued several Shuttle technology areas and the Space Tug (a propulsion stage for moving objects from one orbit to another) as potential avenues of participation. ELDO viewed this as an opportunity to save the organization and give it new purpose. ESRO, which had achieved some success in building scientific satellites, leaned more strongly toward the Space Station and its scientific payloads as its favored arena for cooperation. In the meantime, European industry had participated with American industry in the definition phase of the Space Shuttle and had hoped for a significant European role in this arena. Despite these differences in motivation and background, ESRO and ELDO established a joint working group led by Jean-Pierre Causse and Hans Hoffmann of ELDO and Jean Albert Dinkespiler and Dr. Johannes Ortner of ESRO to study the various alternatives and to present an objective review of the opportunities and challenges to ESC and its member nations. In addition, an ESC office was opened in Washington, D.C., to provide continuous liaison during the discussion period. Jean Lagarde from ESRO was the first person assigned to this office, and he was soon joined by Dr. Christian Reinhold from ELDO.

It was also important to both Europe and the United States to learn more about the other's plans and capabilities. To this end, program and study reviews were opened to representatives from across the Atlantic. Dr. Paine had another discussion with the responsible European ministers in April 1970. Special colloquia were established to facilitate the transfer of information. On June 3 and 4, NASA presented a series of briefings on its Space Station planning at the Grand Hotel in Paris to some 300 European scientists and space program authorities. The key people in the European sponsorship of this meeting were Professor G. Puppi, Chairman of the ESC Committee of Senior Officials; Professor H. Bondi, Director General of ESRO; Professor P. A. Sheppard, Chairman of the ESRO Scientific and Technical Committee; and Professor H. C. Van De Hulst, Chairman of the ESRO Council. Dr. Paine led the NASA delegation, which consisted of key NASA Headquarters program representatives, joined by North American Rockwell and McDonnell Douglas presenters of the current Space Station configuration concepts.

The briefings were very successful. At the end, NASA Assistant Administrator for International Affairs Frutkin summarized the status of cooperative programs to date and invited the Europeans to participate in a variety of meaningful ways. Certain principles were expected to govern any cooperative effort: self-funding of participation, management integrity, adequate exchange of technical information, equivalent access to space facilities, and the broadest possible participation. Based on these principles, opportunities were offered for cooperation in the following areas: studies, supporting research and technology, development of essentially separable elements of a total system, development of essential integral elements of a total system, and utilization. Frutkin concluded by urging that timely decision making was essential, and the more complicated the scope of participation, the more urgent the requirement for an early decision.

Following this meeting, the European scientists met for a series of discussions on Space Station utilization. These discussions led to the establishment of payload planning groups in the various space disciplines. A second colloquium was held July 7, 1970 in Bonn, where a NASA team briefed European industrial and space representatives on the Space Transportation System. Whereas the Paris meeting had been led by ESRO because of its focus on the Space Station, the Bonn meeting was hosted by ELDO and emphasized planning and concepts for the Space Shuttle and Space Tug.

A significant step was taken at the next meeting of the ESC ministers in Brussels, July [illegible]-24, under the chairmanship of Theo Lefevre, Belgium's Minister for Scientific Policy and Programming. A resolution was passed directing the chairman to study with the U.S. government the political, financial, and other implications of eventual European participation in the post-Apollo program. The resolution proposed a meeting with U.S. authorities in September to discuss two main items:

(1) General outline of reciprocal objectives; analysis of the principles on which European cooperation in the American space program should be based; essential problems of the availability of boosters for European programs of scientific research and practical applications.
(2) Study of the character and modalities of the European participation, including the following issues:
    (a) Necessity for the possibility of originality in the European participation.
    (b) European participation in the decision-making process for the complete program.
    (c) Composition and power of the political and technical liaison groups.
    (d) Size of the European participation.
    (e) Reciprocal access to information and facilities.
    (f) Discussions of possible fields of collaboration.
    (g) Other possibilities for space cooperation.

The U.S. Department of State promptly replied that it would be pleased to receive Minister Lefevre and his party, and the subsequent meeting was held in Washington, D.C., on September 16 and 17. Minister Lefevre was accompanied by Lord Bessborough of the United Kingdom and Professor J. F. Denisse of France, along with other representatives from ESC and from the respective ministries of the principals.

The U.S. delegation was led by the Honorable U. Alexis Johnson, Undersecretary for Political Affairs, Department of State, who was assisted by Dr. George M. Low, Acting Administrator of NASA (following the recent resignation of Dr. Paine); Dr. Edward E. David, Jr., Science Advisor to the President; William A. Anders, Executive Secretary of the National Aeronautics and Space Council; and John H. Morse, Deputy Assistant Secretary of Defense for European and NATO Affairs. Advisors from the various U.S. space-related agencies were also in attendance.

The meeting was understood to be the first political-level discussion and would be preliminary and exploratory in nature. Nevertheless, it was recognized that ESC had already taken a number of steps to prepare for a decision on cooperation including a July agreement the ELDO and ESRO would be combined into a single European space organization. In actuality, the convention to establish the European Space Agency (ESA) was not signed until 1975, and legal existence did not take place until ratification of the convention in 1980.

The meeting was amicable and productive, with open, conciliatory discussion on all points as proposed by the Europeans. It became clear, however, that the availability of launch vehicles and launch services was a key factor for further decision making in Europe. Subsequently, Undersecretary Johnson, in a letter to Minister Lefevre on October 2, 1970, summarized the U.S. position. He expressed a fairly strong blanket guarantee of launch services on the assumption that the European cooperative effort would be substantial (at least 10 percent of the resources required to develop the Space Transportation System). With respect to decision making and management, the letter recognized a substantial role for Europe commensurate with its investment and responsibilities. Finally, it expressed the need for access to information and facilities at two levels: detailed access to accomplish specific tasks, and general access to all technology and facilities in the overall development of the program. Undersecretary Johnson concluded his letter with some approximate cost estimates for development of the Space Shuttle, Tug, and Station, some comments on possible third-party participation (particularly by Canada, Australia, and Japan), and an offer to conduct further discussions. It was indeed a very strong and positive letter.

The text of the Johnson letter and the report from the European delegation were presented to the European Space Conference at its next meeting in Brussels on November 4, 1970. ESC unanimously expressed its satisfaction with the encouraging prospects for Europe and its appreciation for the understanding shown by the U.S. delegation regarding matters of concern to the European countries. More specifically, West Germany, Belgium, Spain, France, Italy, the Netherlands, and Switzerland asked for talks in greater depth with the U.S. government. The United Kindgom expressed a desire to participate in the talks, primarily because of its concern over availability of launchers, but only as an observer on post-Apollo subjects.

These conclusions and a proposal for a second meeting in February were conveyed in a letter from Minister Lefevre to Undersecretary Johnson on January 21, 1971. Again, the State Department responded quickly and affirmatively with a letter dated February 5 to Minister Lefevre agreeing to a second meeting in Washington on

February 11. It was evident, however, that the guarantee of launch services was becoming a difficult issue, particularly with respect to the Intelsat agreement and potential launch of European telecommunication satellites separate from Intelsat. The existing agreement, to which the U.S. and European countries were signators, provided a virtual monopoly to Intelsat for communications satellites, and Europe considered Intelsat to be dominated by the U.S. Europe wanted a guarantee that U.S. launches would be available for European satellites with near-term commercial implications even if they were in competition with U.S. satellites. The question was also raised by the U.S. as to whether European requests for technology referred to launch vehicle technology or whether a broader range of technology might be involved.

The expanded European delegation for the February 11-12 talks was again headed by Minister Lefevre and included Minister C. Ripamonti of Italy, Professor J. F. Denisse of France, Dr. Wolf J. Schmidt-Kuester of West Germany, A. W. Goodson of the United Kingdom, F. J. Vollaure of Spain, and E. A. Plate of the Netherlands. ESC advisors and representatives from the seven participating countries rounded out the European team. The principals for the U.S. team were the same as before except for Dr. Maurice J. Mountain, responsible for export control policy, who represented the Department of Defense in place of John Morse. A substantial team of U.S. advisors provided support.

NASA Acting Administrator Low made it clear in his preparations for this meeting that NASA strongly favored large multilateral programs for cooperation, as opposed to scattered bilateral tasks. He emphasized that the former were of greater political value, were easier to manage, provided a coherent technical challenge to Europe, and reduced the risks on costs and schedule. He also expressed satisfaction that technical talks were to be initiated within a few days of the political meeting by representatives from ESC and NASA.

With respect to the six discussion points posed by the Europeans, the following U.S. positions were made clear:

(1) The U.S. would not abdicate its international responsibilities to Intelsat by launching U.S. vehicles abroad (for communications satellite purposes).
(2) Licensing of U.S. launches abroad (for other purposes) was, however, feasible.
(3) General access to all technology would be provided, but commercial-level only as required for European participation.
(4) Priority access to the Space Transportation System would be provided for the participants.
(5) Modalities of participation would be negotiated jointly.
(6) Financial commitment was to be a proper subject for detailed consideration in an agreement.

That these positions were not completely accepted or understood during the course of the meeting was reflected in Minister Lefevre's letter of March 3 to

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Undersecretary Johnson. The European view of the situation at this time was far less encouraging than after the first meeting. In particular, the biggest possible stumbling block appeared to be Europe's uncertainty regarding the availability of launchers for its telecommunications satellite program. Second, the Europeans wanted assurance that there would be an ongoing role for whatever system element Europe developed in the Space Transportation System and no parallel development of the same element on the American side. From a financial standpoint, Europe again stated its desire to define a commitment within acceptable limits and to secure reciprocal subcontracts. Thus, any subcontracts which Europe had to place within the U.S. would be balanced by similar contracted efforts in Europe for the Space Shuttle development. Finally, Europe expressed its concern that restrictions on technology exchanges appeared to preclude the establishment of a true joint venture.

Six months elapsed before Undersecretary Johnson's response to Minister Lefevre on September 1. This gap suggested that some soul-searching took place within the U.S. delegation, particularly with respect to its stand on launcher guarantees. The new response took pains to uncouple the post-Apollo agreement as any condition for launcher guarantees. Instead, it set forth an unambiguous statement aimed at providing a basis for confidence in Europe in the availability of U.S. launch assistance. With respect to post-Apollo cooperation itself, the letter stated that the U.S. positions were the same as conveyed in the letter of October 2, 1970 and as expressed in the meetings of the previous September and February. Finally, the Undersecretary suggested broadening the earlier suggestion for a joint expert group to conduct technical discussions. The group would define possible cooperation in development of the Space Transportation System, exchange views regarding space activities in which Europe might wish to participate, and address open questions relevant to such participation. Charles W. Mathews, then NASA Deputy Associate Administrator for Manned Space Flight, was designated to head the U.S. team.

Soon thereafter, Mathews and Capt. Robert Freitag, long-time NASA official who had been instrumental in many of the early negotiations on post-Apollo activities, led a small team of NASA experts to visit several European companies involved in space studies and concluded their visit with an updated presentation to the Committee of Alternates (Deputy Ministers) of the European Space Conference on October 22. Freitag later recalled that this visit seemed to reflect a major positive shift in the European attitude toward the post-Apollo program. In the 16 months since the first NASA briefings in Paris, significant changes had occurred in the post-Apollo program. ESRO had already conducted some 15 applications studies related to experiment modules and Shuttle payloads. ELDO had sponsored 14 technology activities in areas related to the Shuttle development and its use and had also conducted preliminary studies related to a Space Tug. On the NASA side, the plans for Skylab (a short-term Space Station to be flown in the early 1970s) had solidified, and a two-phase Space Shuttle development was contemplated, though not yet approved. The long-term Space Station plans had been deemphasized, and for the first time, the Sortie Can was highlighted as a potential interim effort. The *Apollo 16* and *17* missions were scheduled to complete the lunar program, and three Earth orbital missions for the Apollo command and service modules were under consideration. This latter effort eventually evolved into a single joint mission with the Soviet Union in the Apollo-Soyuz Test Project. In concluding his presentation, Mathews set the tone for the assignment of the Joint Technical Experts Group, which was, first, to identify the program elements of national interest which would integrate to mutual benefit; second, select specific tasks in development of new space flight capability and in the uses of that capability; and third, propose effective management arrangements. Over the next several months the Joint Technical Experts Group prepared the foundation for a more definitive cooperative agreement. In the meantime, the European community noted with interest the decision by President Nixon to proceed with the development of the Space Shuttle and the subsequent issuance by NASA on March 17, 1972, of a Request for Proposals to U.S. industry for the Shuttle development effort.

Once again, a delegation from the European Space Conference journeyed to Washington for another political discussion with senior U.S. officials, June 14–16, 1972. This time the European delegation was led by Dr. Hans-Hilger Haunschild of the German Ministry, and the U.S. delegation was led by Herman Pollack, Director of International and Scientific Affairs of the Department of State. In preparation for a planned July meeting of European ministers, this meeting was intended to clarify the terms and conditions which might apply if Europe were to formulate a specific proposal for participation in the post-Apollo program. The European delegation was in for a shock.

It was already recognized by most participants in the discussions that a European role in the Shuttle development program was most unlikely, given the technical complexity of the Shuttle design and the importance of the Shuttle to the future plans of NASA, the Department of Defense, and U.S. industry. Nevertheless, the Space Tug was still considered by many Europeans as the most attractive program for European participation. It had the advantage of being a technological challenge as well as a desirable element of the Space Transportation System for synchronous orbit payloads. In any case, at this meeting Chairman Pollack made it clear at the outset that both the Space Shuttle and Space Tug were no longer candidate programs for cooperation. In essence, that left only the Sortie Module (another variation on the name) as a suitable avenue for further consideration, although the Europeans were also urged to make extensive use of the Space Shuttle when it became operational and to participate in payload development, both manned and unmanned.

To this date, arguments abound as to why the Space Tug was ruled out of consideration for European cooperation. Some say it was because the program involved a tremendous technical challenge to develop a high-performance, cryogenic, reusable vehicle in Europe. Others say that the concerns about technology transfer and Defense Department objections were behind the withdrawal. Still others claim that the safety concerns of mounting a cryogenic stage in the Shuttle cargo bay were insurmountable. In any case, the Tug was no longer a subject for further discussions with the Europeans.

The shock to the European delegation was immediate and profound, although some staff participants felt that the U.S. message was not unanticipated. Nevertheless the delegation regrouped, and by the conclusion of the meeting at least some of the members were enthusiastic in supporting the European development of the Sortie Module. It did have certain advantages: it was a less demanding technological challenge than the Tug; the costs would be lower; NASA felt it was a desirable, if not necessary, element of the transportation system; it could provide a vehicle for European scientists' use; and it would perhaps enable European scientists to fly in space.

At the invitation of the European Space Conference, a NASA technical team immediately visited the European Space Technology Center (ESTEC) in Noordwijk, the Netherlands during June 26-30 to share the benefits of NASA studies of the Sortie Module. This was the beginning of a very active period of study and decision making by the Europeans. Three concept definition studies of the Sortie Module were conducted during the next 6 months by European industry under ESRO direction (fig. 8). On August 21 an Aide Memoire was received from the U.S. government stating the new requirements for both NASA and European decisions on a Sortie Module program start. August 15, 1973 was given as the "magic" date on which NASA would have to press forward with initiation of the program, in the absence of a European undertaking, in order to have a Sortie Laboratory available for use by 1979. It stated a readiness, therefore, to accept a firm European commitment in October and signed agreement by late October-early November, along with immediate initiation of a full-scale project definition effort; and an added proviso that the Europeans could withdraw from that commitment by August 15, 1973 if their definition work indicated that the projected target costs would be unacceptably exceeded.

The ESRO Council and the European Space Conference Committee of Alternates within the next month, therefore, revised the proposed study plans to respond to the new U.S. schedule. The new plan laid out a three-part Phase B definition effort, extending from November 1972 to December 1973, but providing the technical proposal and development plan, together with a firm financial proposal by July 1973, prior to the required final commitment date for Europe in August. No firm management plans were presented at this time, but the decision had been made to direct the projected studies from ESTEC, the ESRO technology center.

Activities in Europe during this time period were not solely directed at development of the Sortie Module. Under the direction of J.A. Dinkespiler, Director of Programmes and Plans for ESRO, and his Assistant Directors for Science, Dr. Johannes Ortner, and for Applications, Jean-Pierre Contzen, a number of scientific working groups for Shuttle payload planning had been established. These groups were analogous to the payload working groups established by NASA and addressed the gamut of payloads for the Shuttle. Later they specifically addressed potential European use for the Sortie Lab.

November 8 and 9, 1972 was a period of important decisions within the European space community. First, the space ministers agreed that a plan for a single agency would be formulated by December. Then, the Committee of Alternates informally authorized Phase B studies of the Sortie Lab as a "Special Project." "Special Project" in the context of European space programs means a project in which the member nations *may* participate and to the financial level as *may* be negotiated, as contrasted with the mandatory programs which are supported by all member nations in proportion to an economic formula according to their various financial capabilities. West Germany, Italy, Spain, and Belgium immediately agreed to support this effort, and, soon thereafter, France, the United Kingdom, and the Netherlands agreed as well. Finally, the ESRO Council authorized $7.5 million to support the Phase B effort for the period from November 1972 through July 1973.

On December 20, 1972, at the space ministers' official meeting, the formal development commitment to the Sortie Lab was made. The commitment included an escape clause if, by August 1973, the cost estimates for development were greater than $250 million. In spite of the caveat, this was the approval long awaited. The

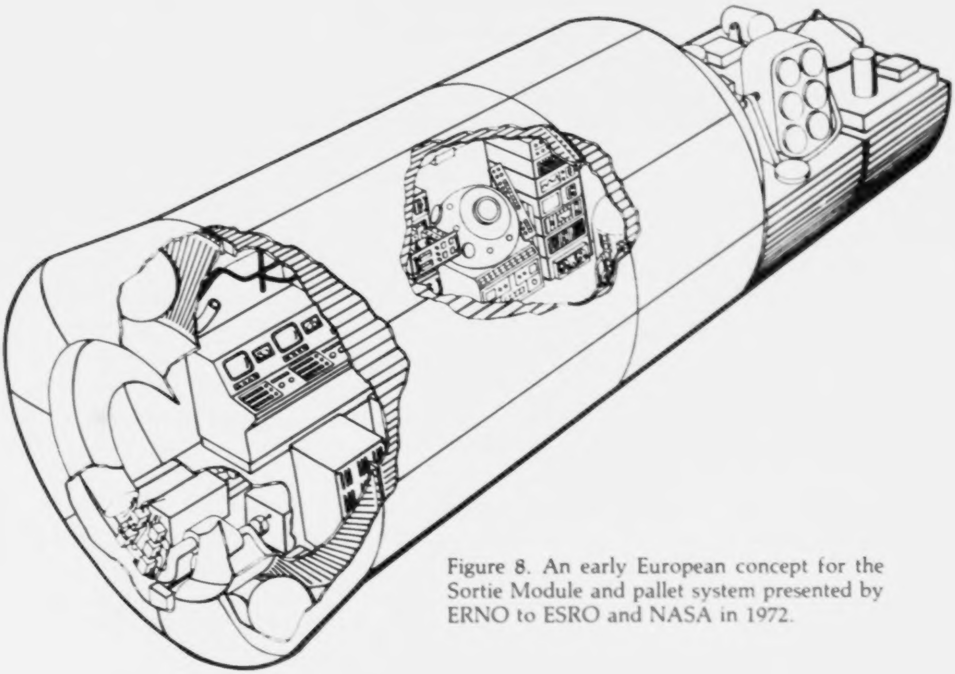

Figure 8. An early European concept for the Sortie Module and pallet system presented by ERNO to ESRO and NASA in 1972.

good news was conveyed to U.S. Secretary of State William Rogers in a letter from Minister Lefevre dated December 29. The ESRO Council met on January 18, 1973 and voted to authorize the establishment of a "Special Project" to develop the Sortie Lab, which by then was called Spacelab by the Europeans. The resolution, passed unanimously by the ESRO Council, authorized the ESRO Director General to negotiate with the participating countries and with NASA the appropriate legal framework for the cooperative program. For all intents and purposes, Europe was under way in post-Apollo.

At this same time, an important symposium was held at ESRO's European Space Research Institute (ESRIN) facility in Frascati, Italy, on January 15-17. The purpose was to acquaint European users with the Sortie Lab (Spacelab) concept. It was well-attended by 250 European scientists and included representatives of many of the NASA-sponsored working groups who provided inputs on parallel U.S. activities. There were the usual suggestions from the scientist participants on how to better use the money, but in the end all the disciplinary groups identified tangible benefits to be gained through the use of Spacelab.

It was apparent from the outset that West Germany was the prime mover in European support of the Spacelab program, and its influence was immediately felt throughout the program. The three industrial consortia (COSMOS, MESH, and STAR) were narrowed to two, both of which were to be led by West German prime contractors (MBB and ERNO). A decision was made against reconstituting the STAR consortium with Dornier System (another important West German contractor) at the helm. Other changes were to be made within the surviving consortia to better reflect the level of support by the participating countries. The projected European Spacelab schedule is shown in figure 9.

Another change made at this time was the replacement of the study manager at ESTEC, Tom Curl, who was of British citizenship. His replacement, Heinz Stoewer, had dual citizenship in the U.S. and West Germany and had been working for the McDonnell Douglas Astronautics Corporation in California.

It was still evident that some major step had to be taken to enlist broader support from the ESRO member nations if Spacelab truly was to become a European effort. At the time of the January go-ahead by ESRO, only West Germany, Italy, Belgium, and Spain were committed partners. On July 31, 1973, the formula was finally discovered. After hours of haggling among the ministers of 11 European countries, a "package deal" was agreed to by the European Space Conference as follows:

(1) The existing European Space Research Organization (ESRO) and European Launcher Development Organization (ELDO) would be merged to form the European Space Agency (ESA).
(2) Spacelab would be developed as a $370-million portion of the post-Apollo program.
(3) An unmanned launcher system (later named Ariane) would be developed under French leadership.

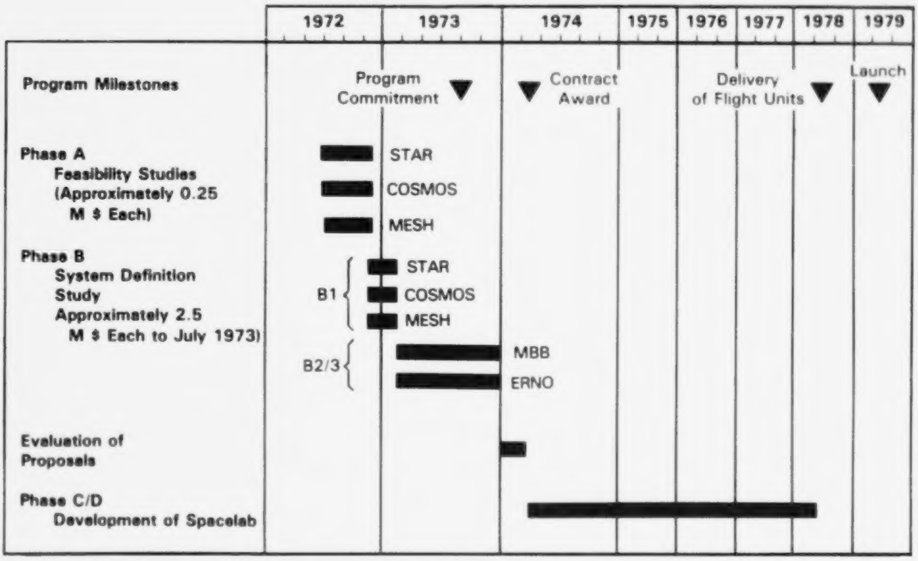

Figure 9. European Spacelab program schedule as of April 1973.

(4) A series of communications satellites (MAROTS), urged by the United Kingdom, would be developed and launched for ship-to-shore transmissions over the important oil routes between Europe and the Persian Gulf.

Thus, in one agreement, ESC had provided something for everyone. More importantly, the big three, France, West Germany, and the United Kingdom, each agreed to give substantial support to all three programs in addition to leadership of its own pet program. The "package deal" was a masterful agreement that was to make possible an aggressive and cooperative space effort in Europe for the next decade.

DEVELOPING THE AGREEMENTS

Before the final commitments were made, activities had already begun toward preparing the agreements which would have to be signed by the participating partners in the Spacelab program. NASA Acting Administrator Low's message of December 28, 1970 regarding the future course of the discussion proposed an in-depth exchange of views and contacts at the technical level. In his letter of January 21, 1971, Minister Lefevre agreed to such an exchange and nominated Jean-Pierre Causse, Deputy Secretary of ELDO, and J.A. Dinkespiler, Director of Programmes and Plans for ESRO, to lead the European team. The first informal meeting of the group was held in Washington from February 16 to 18, 1971, immediately following the February 11-12 political discussions. The NASA team was led by Charles Mathews, Deputy Associate Administrator for Manned Space Flight.

After a hiatus of several months, the Joint Technical Experts Group met in a more formal exchange of views from November 30 to December 3, 1971 in Washington. The group was again led by Causse, Dinkespiler, and Mathews. This time there was more substance to the discussions, though the full spectrum of possible cooperative programs was still covered. Several potential Shuttle work packages that could be subcontracted in Europe were identified, Europe was considering a Phase A study of the Space Tug, a NASA/ESC coordination mechanism was already in place, and Europe was ready to embark on studies of orbital systems as well as their candidate experiment programs. The group also addressed technology needs and management approaches.

A final meeting of the Joint Technical Experts Group was held in Paris, February 8-10, 1972. The NASA team was led by Philip E. Culbertson, NASA Director of Advanced Missions in the Office of Manned Space Flight, replacing Mathews, who had been promoted to the position of Associate Administrator for Applications. This time the group focused on a limited number of work packages suitable for European participation in Shuttle development, reviewed programs of U.S. and European studies, identified the increasing importance of Shuttle sortie missions in the overall post-Apollo program, reaffirmed interest in possible European development of a Sortie Module, and expanded coordination of NASA/ESC Sortie Module studies.

The results of the group's work provided the basic material for a report by the European co-chairmen, Causse and Dinkespiler, to the European Space Conference in March 1972. The comprehensive report included five principal sections: the current status of the Space Shuttle, Space Tug, and orbital systems programs; reasons and justifications for the programs from both the American and European viewpoints; analysis of the various elements for cooperation; management and financing of European participation; and discussion of five program scenarios. The final conclusions of the report were to recommend one of the following three solutions:

(1) Participation in development of the Shuttle to a total sum of about $100 million in the form of subcontracts financed directly by the European governments concerned.

(2) Joint development of the Space Tug by Europe at an approximate cost of $500 million, with subcontracting to U.S. contractors offset by European participation in development of the Shuttle.

(3) Joint development of the Sortie Module by Europe at an approximate cost of $200 million, with the same subcontracting offset as for the Tug proposal.

Immediately after the political discussions in Washington, June 14-16, 1972, at which emphasis was redirected to the Sortie Module, the European Research and

Technology Center (ESTEC) was assigned the task of determining what resources would be required for Europe to develop the Sortie Module (Lab). This task was made difficult by timing (at that time ESC ministers planned to meet and make their decision within a few weeks) and by the fact that ESRO had barely started its own studies of Sortie Lab. To try to help ESRO in this difficult situation, NASA sent a team of nine people, led by Robert L. Lohman, my director of Program Integration in the Sortie Lab Task Force, to ESTEC during June 26-30 to brief the Europeans on NASA design approaches, development plans, and, most important, cost estimates (fig. 10). After three days of briefings and discussions, the team was joined by Dale Myers, NASA Associate Administrator for Manned Space Flight, for an executive session with Dr. Hammerstroem, the ESTEC Director, for a policy question-and-answer session. The key estimate proposed throughout this week of discussions was $250 million (in 1972 dollars) for a European build of the Sortie Lab.

At the conclusion of the team visit, Jean Lagarde, the ESTEC lead systems engineer (and formerly ESC Liaison Representative in Washington), prepared a summary report for ESRO Headquarters, titled "Post-Apollo Program: Sortie Laboratory Assessment." Despite the early protests from the NASA team during the

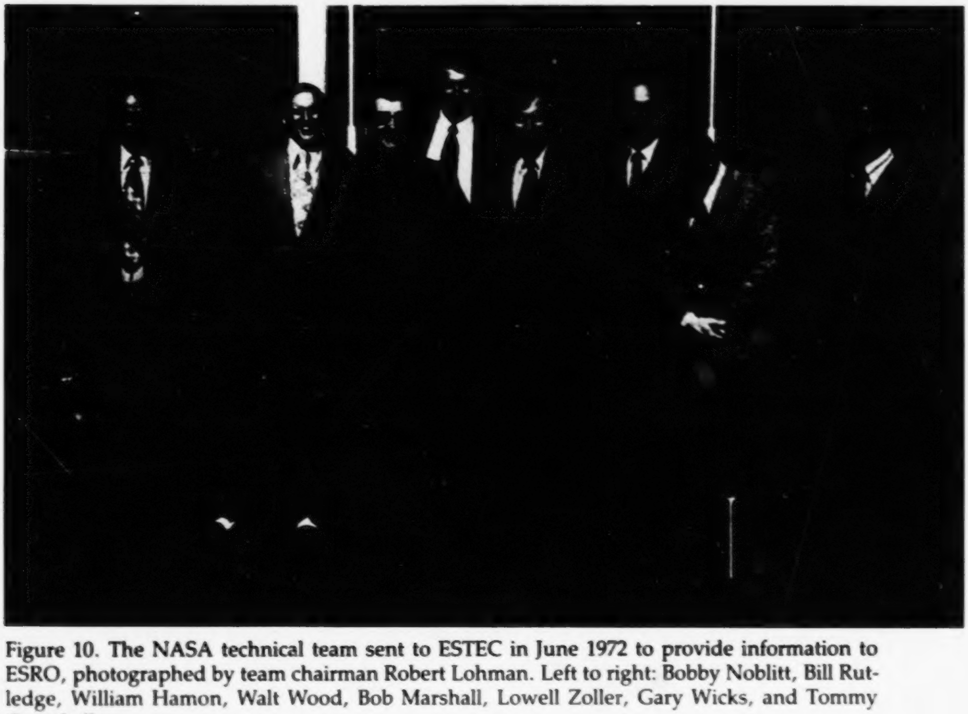

Figure 10. The NASA technical team sent to ESTEC in June 1972 to provide information to ESRO, photographed by team chairman Robert Lohman. Left to right: Bobby Noblitt, Bill Rutledge, William Hamon, Walt Wood, Bob Marshall, Lowell Zoller, Gary Wicks, and Tommy Campbell.

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discussions at ESTEC that the costs were unrealistically low for an inexperienced European team, the final report concluded that the $250-million estimate was a good figure.

While the technical discussions were preparing the way for the detailed content of the European commitment, other groups began drafting the agreement documents for consideration. Based on earlier agreements between Europe and NASA (e.g., ESRO I and II, Helios), both sides first developed a checklist of provisions that might appear in an agency-to-agency agreement. These were first reviewed in a meeting on August 17-18, 1972 at NASA Headquarters. The ESRO delegation was led by Roy Gibson, then Director of Administration for ESRO, and the NASA attendees were led by Arnold W. Frutkin, Assistant Administrator for International Affairs. In addition to a point-by-point review of each other's checklists, the group recognized the need for a government-to-government agreement which would serve as an "umbrella" for the agency-level agreement.

Several issues were raised at this first meeting which would have to be resolved before final agreement could be expected. For example, the issue was again raised by the ESRO representatives as to how a total commitment could be made without a firm technical definition and cost. Other discussions included the detailed responsibilities of each side, adequate coordination including a European voice on the Shuttle change board, and U.S. support to Europe in U.S. procurements. A key point would be the NASA commitment to procure additional Sortie Labs, as needed, from Europe and to agree not to develop a competitive flight system. In general, however, despite these questions, there appeared to be no insurmountable obstacles to developing a workable agreement.

By January 1973, both sides had prepared first drafts of an agency-level agreement, and a second meeting was held at NASA Headquarters on January 9 between Gibson and Frutkin and their supporting staffs. The ESRO format of a Memorandum of Understanding (MOU) was discussed point by point. Gibson then took the assignment to prepare a new draft, which was received on January 23. The similarity of this early draft to the version ultimately signed is remarkable. Except for the sections on customs and liability, which were transferred to the government-to-government agreement, all elements of the January 23 draft are reflected in the final MOU.

Representatives from NASA and the State Department journeyed to Paris for the next round of discussions on February 22 and 23. Frutkin, W. P. (Pat) Murphy (NASA's European Representative in Paris) and I represented NASA, and Bob Packard and John Buehler represented State. On the ESRO side, the team consisted of Gibson, Dinkespiler, Hans Kaltenecker, Ortner, and Jacques Collet. Although the stated purpose of the meeting was to work on the agency-to-agency agreement, the U.S. team got its first look at the intra-European agreement, then in draft form, which would firmly commit the European signers to Spacelab development. It would go into effect whenever two-thirds of the contributors (by funding) had signed. Thus, it only needed signatures by West Germany (contributing 49 percent) and Italy (20 percent) to become effective. Seven countries had made tentative commitments; however France was still awaiting a European decision on a new launch vehicle program, the United Kingdom commitment was formally limited to Phase B2, and the Netherlands commitment was limited to Phase B. ESRO also revealed at this meeting that it had been discussing a skeleton of a government-to-government agreement with the Interim Spacelab Programme Board. Frutkin and Packard offered to provide ESRO with a U.S. draft for its use at the upcoming board meetings on March 6 and 8.

On the principal subject, the agency-level agreement, the major points of discussion were the following:

(1) Ownership—NASA would have rights to use and modify the first flight unit.
(2) Sustaining engineering—ESRO was to provide support through the first two flights.
(3) Responsibilities—Those of each agency were to be stated in comparable level of detail.
(4) Resolution of differences—Some procedure was to be included for arbitration outside the agencies.
(5) Lead time for procurement order—ESRO wanted an order 2 years before delivery of the first flight unit.

Now it was time to consider the government-to-government agreement, which would have to be signed by all the participating countries in Europe and by the United States. On May 3 and 4, representatives from Belgium, France, West Germany, Italy, the Netherlands, Spain, and the United Kingdom came to Washington for a meeting at the State Department to negotiate the draft intergovernmental agreement and the related draft NASA/ESRO Memorandum of Understanding. Most of the fundamentals were readily accepted: ESRO would develop the Spacelab, NASA would operate it; ESRO would deliver to NASA a fully functional engineering model and a flight unit, NASA would purchase from ESRO any additional units it needed; each side would bear its respective costs; coordination, liaison, and reviews would be provided. Some of the other points were more difficult to negotiate. For example, there was the issue of what to call the program. In the U.S. it was still being called the Sortie Lab, whereas in Europe the name Spacelab was preferred. As a matter of principle, neither side would give in, at least until a final commitment was made. Therefore, the agreements used the term "SL" throughout the text.

More important were issues such as when the Europeans must deliver the flight unit. Although it was anticipated that the Shuttle would become operational in late 1979, the Spacelab flight unit was to be delivered 1 year prior to the first operational Shuttle flight. This would turn out to be a valuable cushion to the program as Spacelab development problems occurred and the slips in the Shuttle schedule permitted a corresponding delay in Spacelab delivery.

Another issue related to the European desire for reciprocity in subsystem procurements. The Europeans successfully argued for inclusion of a clause that the Shuttle program give full recognition to the availability of components and services in Europe. This turned out to be a token gesture with little effect in the actual Shuttle development program. It was recognized, however, that changes in the Shuttle program could cause a disproportionate impact on the Spacelab program, which NASA would attempt to avoid. The eventual impacts on the program were quite significant.

Technology transfer was also subject to much discussion, for, as previously pointed out, Europe wanted an open-door policy with respect to technology transfer from the Shuttle program. It was finally agreed that both sides would reserve the right to transfer hardware instead of technical know-how, although know-how would be made available as needed to carry out European responsibilties in the program.

The issue of the use of the first Spacelab came in for considerable attention. It was finally determined that the experiment payload of the first mission would be jointly planned. Cooperative use would be encouraged thereafter, but not to the exclusion of cost-reimbursable use. This provision would receive much adverse publicity at the time of the first Spacelab mission many years later.

Another key element which was included to the delight of the Europeans was the opportunity for European crew members. The agreement specifically stated that a European crew member was contemplated for the first Spacelab flight. On the other hand, the subject of ownership of the first flight unit was studiously avoided. Nevertheless, as Arnold Frutkin stated, "NASA has all the perquisites of ownership." The wording of the agreement was such that, in order to assure the integrity of operation and management of the Shuttle system, NASA shall have full control over the first Spacelab unit after its delivery, including the right to make final determinations as to its use. It also stated that NASA may make any modifications to the first Spacelab which it desired.

While these discussions were ongoing between Europe and the U.S., a similar set of negotiations occurred within the member nations of ESRO to develop the "Arrangement" concerning the European execution of the Spacelab program. This agreement established a Spacelab Programme Board to oversee the cooperative effort among the participating countries, established the financial envelope for the program, authorized ESRO to act as representative and established the percentage share of contributions from the participating nations. One of the most significant requirements was the specification that contracts on the program were to be distributed among the participant countries corresponding to their percentage of contributions. Later this was to provide some interesting and difficult decisions during the management of the Spacelab program.

On July 30, 1973, the Interim Programme Board for the European Spacelab Programme met and approved the text of the intergovernmental agreement, the text of the Memorandum of Understanding, and a draft budget. The following day the European Space Conference met. As a result of this meeting, about 80% of the proposed costs of the program had been subscribed, and it was anticipated that Italy would subscribe to the final 20 percent. (It eventually accepted responsibility for 18 percent.) Because of this last uncertainty, final go-ahead was deferred from mid-August to late September. On August 1, the ESRO Council met and endorsed the decisions of the previous 2 days.

One other group played a significant role in concluding the agreements. At the direction of senior NASA and ESRO officials who convened in Washington on November 22, 1972, a Sortie Lab Working Group chaired jointly by Dr. Johannes Ortner, ESRO Assistant Director for Space Missions, and me, Director of the NASA Sortie Lab Task Force, held its first meeting on November 30, in Washington. This group was a continuation of the committee I co-chaired with Ortner during the previous 2 years to coordinate technical activities on orbital system studies. Our new assignment was to coordinate all technical activities related to the Sortie Lab/Spacelab program under way in the United States and in Europe. At its first meeting, the NASA/ESRO working group addressed six issues: ESRO Phase B study plans, decision process and milestones, communications requirements, representation at each other's sites, ESRO needs for on-site assistance, and levels of U.S. involvement. At a second meeting in Paris on January 12, 1973, the working group reviewed proposed configurations, a draft of the top-level Guidelines and Constraints document, contents and schedule for preparation of a Joint Preliminary Project Plan, ESRO needs for special NASA studies, schedules for document availability, representation on Shuttle change boards, and levels of U.S. involvement.

By the third meeting of the group on March 22–23, 1973 in Washington, some significant personnel changes had been made. Jean-Pierre Causse, formerly of ELDO, had been named ESRO's head of the Spacelab program and, therefore, replaced Dr. Ortner as the ESRO Committee Chairman. Heinz Stoewer had replaced Tom Curl as the ESTEC representative, and Thomas J. (Jack) Lee had replaced Jack Trott as the NASA Project Manager for the Marshall Space Flight Center. The name of the group was soon changed to the Joint Spacelab Working Group, as it would be called in the Memorandum of Understanding, and the seemingly unpronounceable acronym JSLWG was soon being pronounced as "Jizzlewig."

The working group had three more meetings in 1973 before the final agreements were signed. These meetings on May 10 in Paris, July 16 in Washington, and September 11 in Paris continued to review the progress of the ESRO Spacelab studies and to complete documentation needed to support the program. Probably the most important of these documents was the Joint Programme Plan, the preliminary version of which was signed by Causse and me on July 30, 1973 and which was referenced in the NASA/ESRO Memorandum of Understanding to amplify in greater detail the MOU's more general descriptions, phasing, scheduling, and working arrangements. Within the Joint Programme Plan, the section that received the most attention concerned which agency was in charge of the various facets of the program and what level of involvement the other agency would have. At the lowest level of involvement an agency would only provide information to the other; at the next level, the agency would monitor the activity; at the highest level, the agency would review and approve the item. Items covered a broad spectrum from requirements and documentation to interfaces and activities (e.g., engineering, manufacturing, program control, and testing). What made the decisions doubly difficult was that in many cases the level of involvement would change in the development phase from what it had been during the definition phase. As is often the case in a new program, many of the problems of responsibility which had seemed so critical at this formative stage were no longer a problem once the program was under way. Good sense and cooperation usually prevailed.

At last it was time to sign the agreements. In Europe on August 10, 1973, Belgium, France, West Germany, Switzerland, and the United Kingdom endorsed the "Arrangement Between Certain Member States of the European Space Research Organization and the European Space Research Organization Concerning the Execution of the Spacelab Program." Subsequently, the Arrangement was also signed by the Netherlands, Denmark, Spain, and Italy, and sometime later, Austria.

On August 14, Belgium, France, West Germany, Switzerland, the United Kingdom and the United States signed the intergovernmental agreement titled "Agreement Between the Government of the United States of America and Certain Governments, Members of the European Space Research Organization, for a Cooperative Program Concerning the Development, Procurement, and Use of a Space Laboratory, In Conjunction with the Space Shuttle System." The Netherlands signed on August 18, Spain on September 18, Italy on September 20, and Denmark on September 21. Again, Austria joined at a later date and so was not included in this first round of signatures. On the same date that the first signatures were obtained on the intergovernmental agreement, ESRO and NASA initialed the "Memorandum of Understanding Between the National Aeronautics and Space Administration and the European Space Research Organization for a Cooperative Program Concerning Development, Procurement, and Use of a Space Laboratory in Conjunction With the Space Shuttle System." This was a symbolic gesture in order to meet the previously set deadline for a European commitment by August 15, 1973.

The stage was set for the triumphant conclusion to years of negotiation and preparation. On September 24, in a ceremony at the Department of State in Washington, Acting Secretary of State Kenneth Rush and the Honorable Charles Hanin, Belgian Science Minister and Chairman of the European Space Conference, signed a communique, that noted the completion of arrangements for European participation in the Space Shuttle program and marked the beginning of a new era in U.S.-European space cooperation. In the same ceremony, Dr. James C. Fletcher, the NASA Administrator, and Dr. Alexander Hocker, Director General of the European Space Research Organization, signed the Memorandum of Understanding to implement this unprecedented international cooperative project (fig. 11). Unfortunately, the European minister who had worked so hard to bring about this marriage, Theo Lefevre, did not live to witness the fulfillment of this dream.

Only one incident casts a shadow on the signing of these historic agreements. Questions were raised by some representatives of American industry, in particular an aerospace union organization, as to why it was necessary to give part of the

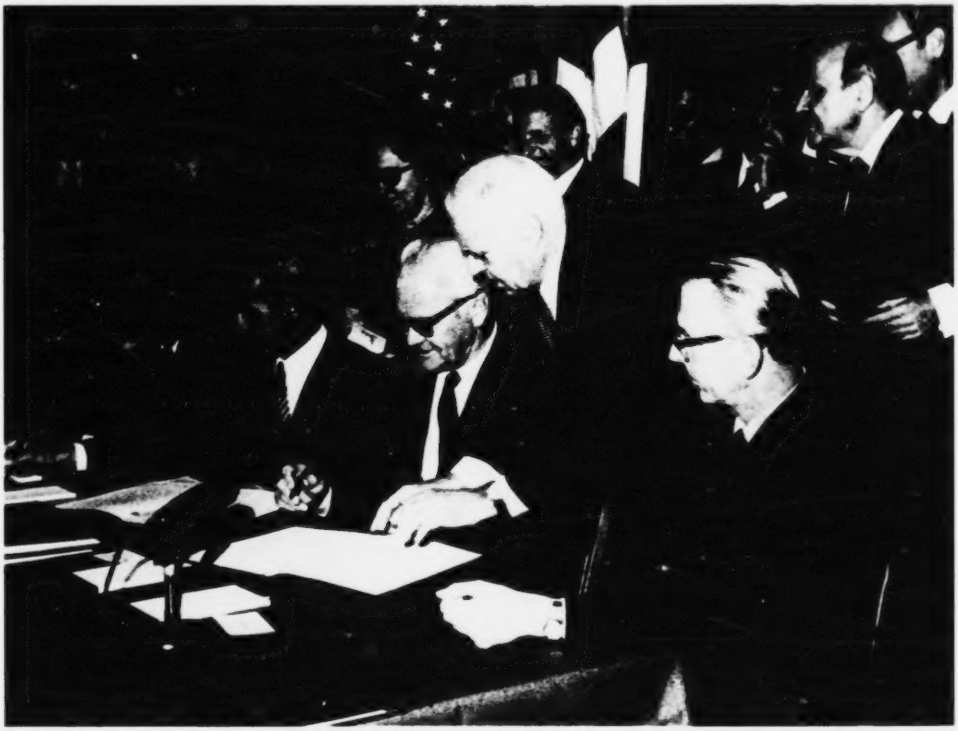


Figure 11. Ceremony at the Department of State, Washington, D.C., September 23, 1973. Right to left: NASA Administrator James C. Fletcher; Acting Secretary of State Kenneth Rush; the Honorable Charles Hanin, Belgian Science Minister; and Alexander Hocker, ESRO Director General. Representatives of the participating European nations are in the background.

Space Transportation System to European industry for development. When it was made clear that no U.S. contract dollars would go to Europe and that we were unsure when we could fund Spacelab in this country, objections quickly subsided. In actuality, Spacelab eventually generated many subcontracts in the U.S. from European developers, as well as significant NASA-funded support contracts. This was clearly a positive step forward for all.

Personal Reflections

The period from 1969 to 1972 was an exciting time for those in NASA and the aerospace industry who participated in the Space Station studies. We were all convinced, naively as it turned out, that this time the Space Station was really going to get started. Following the tons of reports generated by the study efforts, an unofficial report created by a member of the McDonnell Douglas team best describes our feelings: "A Funny Thing Happened On the Way to the Space Station." This little book of cartoons drawn from shared experience reflected our frustrations that, once again, the Station would be postponed.

It was not all a lost effort, however. I recall at the 1970 Ames conference the thrill of getting to know Raymond Loewy, the renowned industrial designer, who was so excited about the opportunity to apply his creative mind to the problems of living in outer space. The ideas which he and his associates generated later made the Skylab workshop a more pleasurable living experience for its crews. Loewy's thoughts about the relationship of living areas, and of textures and colors, were truly imaginative.

The Ames Airborne Science Program using the Convair 990 and Lear Jet was also a very interesting undertaking. I still recall with excitement the opportunity I had to fly on one of the CV 990 missions from Wallops Island to the vicinity of Bermuda and back, watching the astronomers and technicians on board as they observed the heavens from their vantage point well above much of the Earth's atmosphere. I found it difficult to comprehend the vast number of stars displayed on their instrument monitors. What a thrill it must be today for scientists to observe these phenomena from the Spacelab, where the atmosphere is nonexistent and atmospheric turbulence cannot disturb their platform nor obscure their observations.

Brilliant leadership was provided by NASA Administrator Thomas Paine and his international program head, Arnold Frutkin, in offering the opportunity to Europe for a cooperative role in the post-Apollo program. In their first visit to Europe, Frutkin tried to curb Paine's enthusiastic description of a 100-man Space Station for fear it would make his projections appear less credible. Later, when we were preparing for 2 days of briefings in Paris in June 1970, it became obvious that there was not enough room on the crowded agenda to pack all the information desired into the time available. Paine suggested that perhaps sandwiches could be brought in for a working lunch. Others recognized that this just could not be done in the Grand Hotel in Paris! Despite such cultural differences, the optimism and openness of Paine and his NASA team were infectious, and the Europeans were quickly caught up in the mood. Perhaps the most important statement at that briefing was made by Frutkin: "The train was leaving the station." In other words, if the Europeans wanted to participate, fine; if not, we would go on without them.

It would be wrong to say that there was no disappointment on NASA's part when the Space Station was postponed and when it became evident that Europe would develop the Spacelab. On the other hand, we were excited about the prospect of international cooperation and delighted that a reusable laboratory would be available when the Shuttle became operational.

We knew, however, that this would be a new ball game. There would be, in essence, two heads of the program—one in NASA and one in ESRO. NASA would have to set the specifications for the new system and in the end would be expected to operate it in conjunction with the Shuttle. The Europeans would provide the development funds and would design, manufacture, and test the entire system before we would get our hands on it. It was as if NASA had hired a development contractor, only in this case the contractor was in Europe and would use its own money. Clearly, ESRO could not be treated like the usual NASA contractor.

The first job was to get acquainted and to make sure that information already developed by one partner was made available to the other. ESRO representatives were soon making regular trips to NASA Headquarters and field centers to review our studies and supporting technology activities. In a similar fashion, NASA groups began regular trips to the ESRO head office in Neuilly, near Paris, and to ESTEC in the Netherlands. The ESRO team was experienced in international travel, and most were multilingual. For those of us in NASA, however, this was a new and interesting experience. A new dimension in jet lag, the experience of changing currencies, our lack of language expertise, unusual foods and eating habits, an opportunity for sightseeing in famous places, different customs in dress and entertainment, and a completely new approach to contract management were all aspects of the program that most of us were completely untrained to handle.

Some of us tried to augment our high-school French with crash courses and tutors but at best this only enabled us to improve the quality of dining in Paris and helped us find our way around. After I had been served salami instead of salmon I thought I had ordered and, on another occasion, when I ordered the plate of the day, just to be safe, and received calves brains, I learned to carry along a "Menu Master" in order to avoid such surprises. Before long, we were avoiding the pitfall of *rognons* (kidneys) and *ris de veau* (sweetbreads). I soon became the recognized NASA team expert on French cuisine and later published "Le Lord Guide Des Bons Restaurants de Paris," which was very useful to NASA visitors to this wonderful city. I also became the acknowledged expert on the Paris subway, the *Metro*. Finding that this was a quick and economical way to get around the city, I studied it in some depth (no pun intended) and instructed each new NASA visitor in how to stretch travel funds by buying a carnet of tickets which would take one any place within the city for about a quarter. By the time of my retirement in 1980, my knowledge of and affection for the system was so recognized by my ESA friends in Paris that they presented me with a number of *Metro* mementos, including a conductor's cap and a ticket punch. Needless to say, I was delighted.

Another challenge to me was the problem of what to drink in Europe. Some of my cohorts felt that Europe was wasted on me, a teetotaler, because I couldn't appreciate the fine wines and beers that were always available, sometimes even on the conference tables during our meetings. Although I must confess I started out on my first trip drinking melted water from the ice bucket, I soon learned that bottled water (plain or bubbly) and fruit juices were always available. Another European tradition was the appearance in the middle of the morning and afternoon meetings of trays of expresso coffee in demitasse cups. Although it was sometimes cold when it arrived and looked as if it were strong enough to walk in by itself, it was enjoyed by the coffee drinkers among us. Of course, Coca Cola had preceded us all over Europe, so it was available when all else failed.

ESRO Headquarters, located in an office building in Neuilly-sur-Seine, was an interesting place to visit. On certain days, outdoor markets were set up in the wide boulevard in front of the building, and it was fascinating to visit the stalls and see the splendor of the fresh fruits, vegetables, meats, and flowers. By noontime all would be sold or moved on, only to reappear anew at another market site the next day. Nearby cafes, pastry shops, and candy stores introduced us to the marvels of French croissants, croque monsieurs, and bon bons. A short walk would take us to the Jardin d'Acclimation, a pleasant park of the Bois de Boulogne, complete with children's rides, a zoo, and scenic walkways. The Bois de Boulogne itself is a huge area with restaurants, jogging and hiking trails, horseback riding, racing tracks, a spectacular rose garden, and the inevitable ladies of the night standing along the curbsides.

The European Space Technology Center, ESTEC, is a large complex of interconnecting buildings located by the North Sea and dunes just south of Noordwijk in the Netherlands. Modeled in some ways after NASA's Goddard Space Flight Center, ESTEC's laboratory and testing facilities include the latest in heavy-duty shakers and thermal vacuum chambers for the verification of space components and satellites. Noordwijk is a small seaside resort with many waterfront hotels and a delightful walking street of shops and restaurants. During a stay in one of these hotels, I was awakened in the morning by the pounding of stakes in the sand as wind breaks were set up for hardy locals and vacationers who take advantage of the slightest break in the weather to sun and swim.

Located in the center of the Netherlands' tulip-growing area, Noordwijk provided us with a marvelous view of the hardy Dutch and their way of life. The bicycle paths were crowded with laughing schoolchildren in the mornings and afternoons and used by all ages at other times, pedaling their very unglamorous black bikes in total defiance of the strong winds and teeming rain or sleet. More than one NASA visitor became confused by the extra traffic lights and pavement for these paths and found himself driving a rental car up the bike path. We were also surprised to find that in recent years the Dutch climate had prevented the canals and lakes from freezing.

When a freeze did occur, the canals were quickly covered by children and adults using every available sliding device including wooden strap-on ice skates.

During tulip season, the fields around ESTEC presented a breathtaking vista with vast expanses of brilliant colors, and a visit to Keukenhof Gardens in nearby Lisse provided an opportunity to see the very finest blooms from every major bulbgrower. When the fields reached their peak of color, the blooms were removed to stimulate development of the bulb and the petals were hauled away in canal barges, or fed to the livestock, or made into colorful garlands to be sold from roadside stands. A working windmill and even a hardy old soul wearing wooden shoes could occasionally be seen in some areas.

Several of our ESA friends living in or near Noordwijk opened their homes to us. Heinz Stoewer lived on an island in a nearby lake, and it was necessary to take a small ferry to reach his home. Rudy Meiner lived in a former stable of a large estate, which had been converted and decorated in a delightful manner. Frank Sperling lived in a very modern and beautiful home nestled in the dunes. Many of our ESA friends enjoyed sailing, and it could be quite a surprise to see the sails of a boat moving along in the distance when one was unaware there was either a lake or canal in that direction. Some of the boats would have been right at home on the Chesapeake Bay or in Long Beach Harbor, but others were traditional Dutch sailing vessels with large luboards. The canals and lakes in the Netherlands provide a parallel system of transportation to the highways and railroads. In many cases, they are lined with houseboats which provide permanent homes for their occupants.

The early meetings of the Joint Spacelab Working Group were a great learning experience. Though the ESRO representatives were skilled in English, often their usage of terms was different, and it was sometimes difficult for them to maintain pace with our rapid-fire deliveries. On one occasion, my co-chairman, J. P. Causse, threatened to switch to French if I couldn't curb the flood of "Alabamese" he was being subjected to in a presentation by Luther Powell of the Marshall team. "J. P." could be very demonstrative when he wanted to make his point, but I learned to work with him and we developed a strong friendship.

Other early leaders in the program should also be mentioned. Heinz Stoewer, who became the Project Manager at ESTEC for several years, was a very impressive leader during the formative years. He assembled and built the technical team for ESRO, conducted the evaluation of the contractor proposals, guided the transition from the paper to the hardware phase, and stepped in as ESRO program head when Causse departed. Although he left the program before its completion, his contributions during the early years were many. He has since held a responsible position as head of the systems department at ESTEC.

At Marshall Space Flight Center, there were a series of changes in the technical team management. Bob Marshall headed the Sortie Can study phase and, with the assistance of Gary Wicks and others, did a creative and sound engineering job. Fred Vreuls was named to lead the initial task team, but was soon replaced by Jack Trott. After a few months, Trott was replaced by Thomas J. (Jack) Lee, who lent stability to the MSFC program office. Jack remained in this key position for the next 7 years, until he was selected to become Deputy Director of the center. In addition to building up the NASA technical team and its industrial base of support, Jack served as a valuable aid to me, established an effective working relationship with the European Project Manager, selected resident and review team members to be sent to Europe, and provided sound advice and counsel to the development effort. No one contributed more to the success of this program.

The creation of the paper agreements was a very interesting experience for me, never having been involved in international negotiations before. I soon learned that lawyers and diplomats have much in common—they both focus on the literal as well as implied meanings of every word and phrase. Even a comma could be the subject of an hour of debate as we tried to reach agreement on a particular sentence. In at least one instance when it appeared that agreement would be stalled, a late-night marathon session at Washington's Cosmos Club for key members of both delegations was necessary to remove some of the roadblocks. I became very appreciative of the skills and patience of such participants as Herman Pollack and Arnold Frutkin on the U.S. side and Roy Gibson and Hans Kaltenecker on the European side.

Just before the final agreements were signed, I had the idea that a NASA newsletter would be a good idea for the program. In June 1973 the first issue of the Sortie Lab Newsletter appeared with the opening statement: "Because of the geographical spread of our Sortie Lab work force and the broad spectrum of interested participants, some persons may find it difficult to keep up to date on program activities. For this reason, it seems desirable to initiate and circulate a monthly newsletter." Although the frequency of publication varied, and the name was soon changed to the Spacelab Newsletter, the popularity of this publication is attested to by the fact that the first issue had 75 addressees and the final issue in December 1980, had more than 300 persons on the distribution list. I am particularly thankful to Jack Wilhelm and Diana Winslow, who were responsible for starting and keeping the newsletter going through those years. Although there were times when issuance of the newsletter seemed very low on our priority of jobs to be done, and obtaining contributed articles from our busy staff was like pulling teeth, I believe that the newsletter was a valuable tool in keeping people informed about the program and in building the esprit de corps vital to the success of the Spacelab effort. In my writing the story of Spacelab, it has also proven to be a valuable resource. It is through little things like this that big programs are accomplished.

2 Birth of a Concept
1960-1973

Spacelab is a very innovative concept, the product of many engineering and scientific minds and the result of an evolutionary process that began before the first manned missions into space. To better understand the creation of this concept, and the people who were involved, it is necessary to recall the many steps which took us on the path to Spacelab.

BACKGROUND

The 1960s were a time of accomplishment, challenge, and dreams for the U.S. manned space flight program. While the National Aeronautics and Space Administration was at the helm of this activity, its efforts were supported by American industry, particularly the aerospace segment, by the Department of Defense and other government agencies, and by myriad elements of U.S. society, from the White House and Congress to the universities and, ultimately, to the men and women who paid the bills and responded to its accomplishments.

We watched with awe as our first astronauts ventured into orbit in the tiny Mercury capsules. We gained new condidence as the Gemini pilots expanded the duration of flight and succeeded in the critical tasks of rendezvous and docking. Then we held our breath as an Apollo crew, for the first time, disappeared from view around the backside of the Moon. And when those first steps were taken on the Moon's surface, we all shared in the pride of accomplishment. At the same time, an unheralded group of dreamers was looking ahead to more ambitious goals which might be accomplished with men and women in space. This is the story of some of those dreams and the particular path that led to the largest cooperative international effort in the history of space flight.

NASA LONG-RANGE PLANNING

From its inception, NASA has had a cadre of people devoted to looking ahead. Indeed, the very nature of the agency is such that its people are challenged by the unknown. What can we do next? What is out there? What can be done in space for the benefit of mankind? And from the pragmatic viewpoint, how does one keep a large and effective agency, NASA, and its dependent industrial complex engaged in productive activities? These and similar questions have resulted in NASA Headquarters and each of the field centers creating long-range planning groups, establishing difficult program goals, searching for new techniques and missions, and developing the supporting technology necessary to achieve those goals.

In the early 1960s, the NASA Office of Manned Space Flight proposed seven major projects for its 5-year plan. (It is significant to note that there was no mention of a reusable launch vehicle or Space Shuttle.) Each of these projects was considered to be outside the primary thrust of the Apollo program itself. The first project was to obtain lunar data required for design and mission planning for the Apollo program. At that time, the specific unmanned programs under way in this direction were the Ranger, Surveyor, and Micro-meteorite satellite (later to be called Pegasus) programs. All these programs were successful and provided essential information before the initial Apollo lunar missions. Another significant effort, the Lunar Orbiter program, was also accomplished during this time.

The second project proposed was a lunar logistics system, conceived as an unmanned system using Saturn 1B and Saturn 5 launch vehicles to land support payloads on the Moon's surface before and after the first Apollo landing. It was thought that the logistics system would improve the Apollo mission capabilities and probabilities of success by prelanding payloads on the lunar surface. It would be used to provide transport capabilities for the post-Apollo lunar program, such as a manned lunar base. This entire concept was subsequently dropped.

The third proposed project was NOVA, a super launch vehicle twice the size of the Saturn 5, which would be used for manned planetary missions. It was to be compatible with a nuclear upper stage. Although technical development continued for several years on the nuclear engine, studies of the NOVA vehicle never progressed beyond the preliminary phase.

A manned Space Station in near-Earth orbit was the fourth project. Its emphasis was to be on conducting experiments in the space environment, and it would be used to test equipment and crews for long-duration flights. The Station would also be used to maintain and refuel spacecraft engaged in lunar and deep-space missions. Significant study and technology efforts have continued in this direction to the present time. In 1984 President Ronald Reagan directed NASA to proceed with the development of a Space Station, and Congress appropriated significant funding for this purpose.

The fifth proposed project was a manned lunar base. Although studies of such a base continued for several years, the agency gradually lowered its sights in this regard, and the major outputs of the studies were exploration techniques, scientific instruments, geological tools, and roving vehicles that were eventually used on the Apollo missions.

The sixth proposal was directed at propulsion systems for a super-NOVA vehicle, capable of placing 2 million pounds into Earth orbit. Needless to say, studies of such a monstrous vehicle received little support in the ensuing years.

The seventh proposal was for development of a manned planetary exploration capability. This proposal provided stimulus for subsequent studies of missions to Mars and Venus, but as the fiscal realities of the Apollo program became apparent to Congress and NASA, pressures were brought to bear and studies of manned planetary missions were postponed indefinitely.

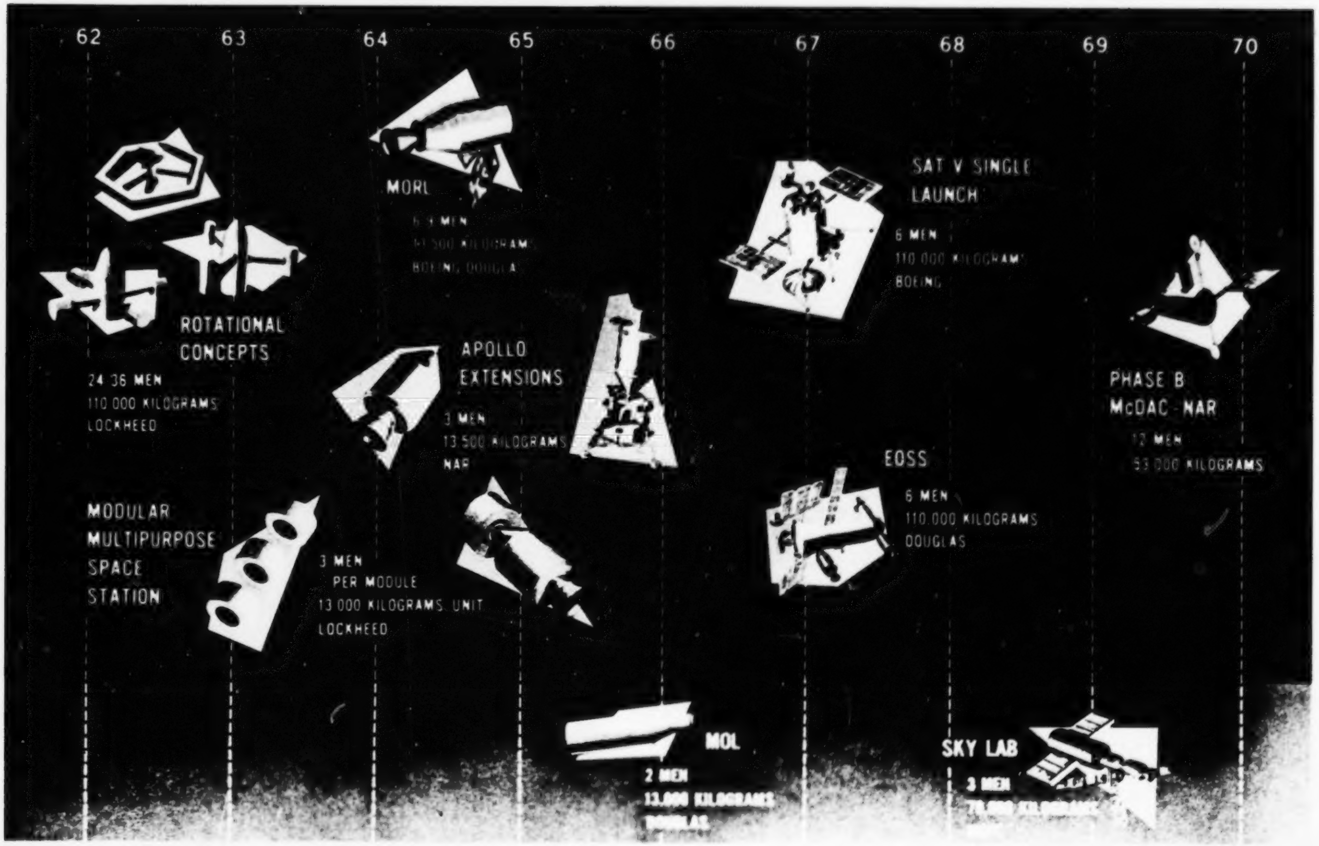
From 1963 to 1967, NASA spent some $65 million on studies of potential manned missions and systems. Some of the studies led down blind alleys or were terminated for lack of support. Others, however, provided the genesis of experiments, launch vehicles, spacecraft, and support equipment that were used in Apollo and Skylab and today are used in the Space Shuttle and Spacelab.

SPACE STATION STUDIES

The area that received the greatest study and support was the Space Station. During the latter half of the 1960s, NASA focused its advanced studies of manned systems toward Space Stations and their attendant logistics support systems (fig. 12). The first tangible success of these studies was the approval, subsequent development, and successful flight missions of the Skylab program. For our purposes, it is sufficient to recall that Skylab was launched in 1973. After initial difficulties, it was inhabited and utilized by three sets of crewmen using the Apollo command and service modules and achieved resounding success in missions of increasing duration. Although the words "Space Station" were carefully avoided during the formative years of the Skylab program, it was, in reality, our first manned Space Station and a remarkable success.

Prior to 1969, most studies of Space Stations were "Phase A" type, a NASA nomenclature which relates to phased project procurement and denotes the exploratory nature of the study. Perhaps the most in-depth study was the one conducted over a 4-year period by Langley Research Center titled the Manned Orbital Research Laboratory (MORL). The purpose here is not to denigrate the importance or value of the many studies conducted by the Manned Spacecraft Center (Johnson Space Center) or Marshall Space Flight Center during this time, but rather to note that most of the studies were at a relatively low level of funding or manpower and thus, of necessity, could not examine most systems to the level required for a hardware go-ahead.

In 1969, NASA management made the important decision to establish Headquarters and field center task forces to begin preliminary design studies for the Space


62
63
64
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66
67
68
69
70
ROTATIONAL CONCEPTS
24-36 MEN
110 000 KILOGRAMS
LOCKHEED
MORL
6-9 MEN
61 500 KILOGRAMS
BOEING, DOUGLAS
APOLLO EXTENSIONS
3 MEN
13 500 KILOGRAMS
NAR
MODULAR MULTIPURPOSE SPACE STATION
3 MEN PER MODULE
13 000 KILOGRAMS UNIT
LOCKHEED
MOL
2 MEN
13,000 KILOGRAMS
DOUGLAS
SAT V SINGLE LAUNCH
6 MEN
110 000 KILOGRAMS
BOEING
EOSS
6 MEN
110,000 KILOGRAMS
DOUGLAS
SKY LAB
3 MEN
70,000 KILOGRAMS
PHASE B
McDAC-NAR
12 MEN
53 000 KILOGRAMS

Figure 12. Evolution of Space Station concepts during the 1960s.

Station and the Space Shuttle. The achievement of the early manned lunar landings and the report of the Space Task Group to President Nixon gave impetus to this action and soon Phase B studies were under way for both projects.

At that time, the Space Station was envisioned as being useful in at least the following ways: to provide direct benefits to mankind in communication and Earth surveys; to provide information to industry from Earth surveys and from materials and manufacturing processes in space; to stimulate technology advances; to encourage international participation; to develop new scientific apparatus where sizable payload capability is required and where manned attendance enhances the operation; to qualify man, his supporting systems, and operations for future penetration of the solar system by manned vehicles; to provide a base in space for monitoring, control, maintenance, and repair of satellites, as well as a way station for deep-space probes; and to support national security.

An industry competition was conducted for Phase B studies for the Space Station, and parallel efforts were initiated by the Space Division of North American Rockwell under the direction of Rene Berglund at the Manned Spacecraft Center and by the McDonnell Douglas Astronautics Company under the direction of William Brooksbank at Marshall Space Flight Center. For the next 3 years these two efforts were to continue with periodic changes in emphasis. In the beginning, each contractor was to develop plans for a modest Space Station capable of supporting 12 persons. In addition, however, they were asked to consider the implications of and approaches to providing artificial gravity, to present a growth capability to a 100-man Space Base, to consider both interim logistics systems using existing or expanded manned spacecraft and an advanced logistics system using reusable vehicles, and, finally, to examine ways in which the Space Station could be used to provide stepping-stone systems for a manned planetary mission (fig. 13).

At the same time that the Space Station studies were underway, a similar preliminary design effort was being conducted for the Space Shuttle. During the next year it became clear that the Shuttle was receiving considerable support as a potential low-cost replacement to the stable of expendable launch vehicles then being used for satellite launches. Its multifaceted capability for satellite placement and retrieval and for carrying upper stages with deep-space payloads, as well as the logistics support of a Space Station, made the Shuttle a strong candidate for top priority in the quest for new budget authority.

Up to this time, the Space Station definition studies had been focused on the Saturn V, the phenomenally successful Apollo launch vehicle, as the carrier to place the basic Station in orbit, since the Station's weight (100 000 pounds or more) and physical size (33 feet in diameter) were too much for any other launch vehicle or the Shuttle. With the increase in popularity of the Shuttle concept, however, it was decided to refocus the Space Station studies on a modular structure that could be launched into space, piecemeal, by the Space Shuttle (fig. 14) Therefore, for the second half of the Space Station Phase B studies, modular was the watchword, and all considerations were dropped of peripheral concepts such as Apollo-type logistics spacecraft, Space Bases, or planetary mission components.

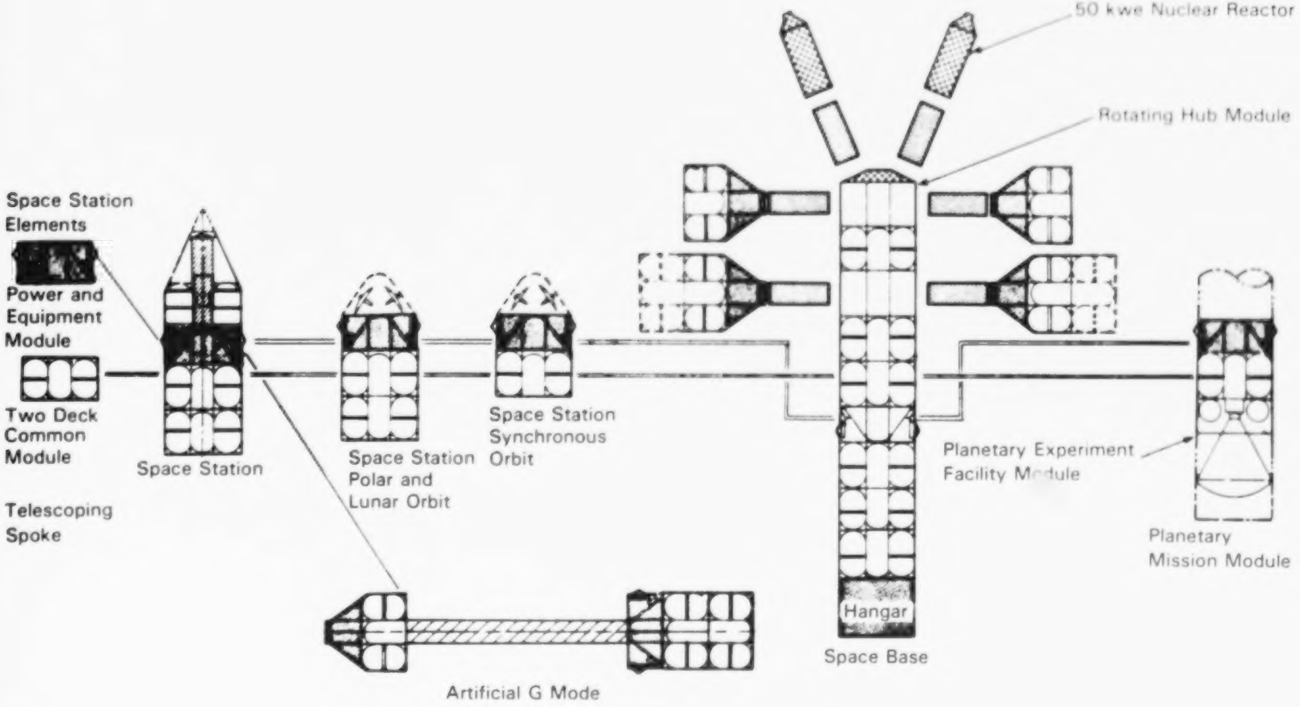

50 kwe Nuclear Reactor
Rotating Hub Module
Space Station Elements
Power and Equipment Module
Two Deck Common Module
Telescoping Spoke
Space Station
Space Station Polar and Lunar Orbit
Space Station Synchronous Orbit
Planetary Experiment Facility Module
Planetary Mission Module
Hangar
Space Base
Artificial G Mode

Figure 13. McDonnell Douglas' common module concept for the evolution from Space Station to Space Base and to Planetary Mission Module.

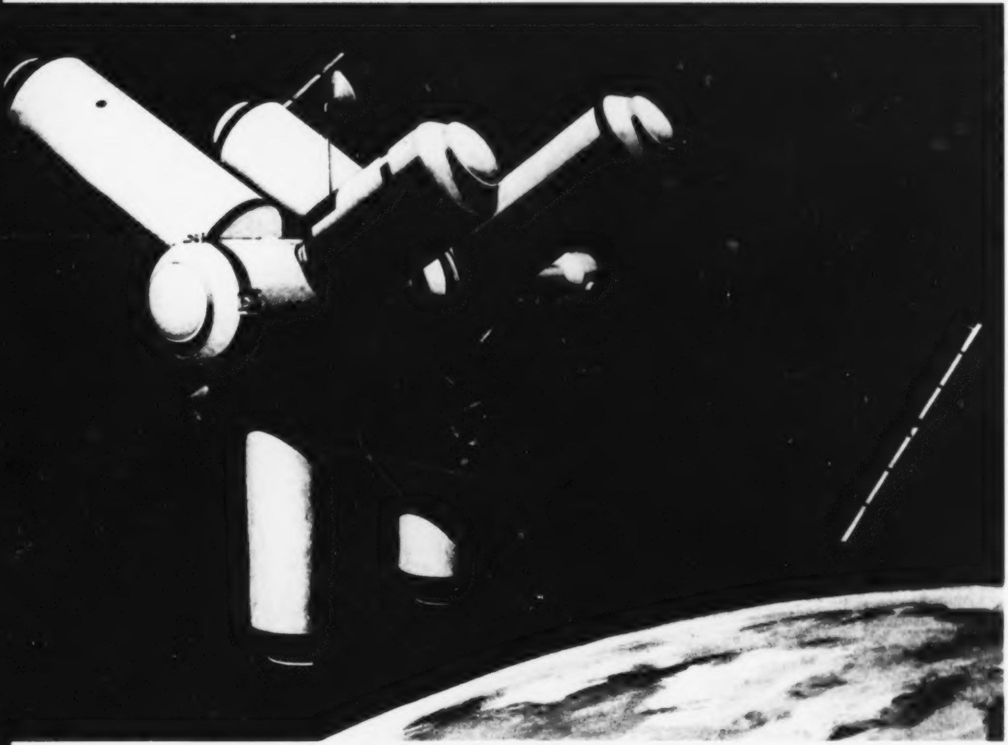


Figure 14. McDonnell Douglas' concept for a modular Space Station which could be assembled from Shuttle-sized components.

The principal study conclusions were that the technology was at hand to develop a permanent Station. Of course, difficult decisions would have had to be made about electrical power (solar versus nuclear), size, rate of buildup, orbital inclination, and rotation of crews, but persons directly involved in the studies were convinced that many of the concepts were feasible, and that the Station would provide worthwhile scientific and technological returns. The key to the Space Station would be a low-cost logistics support system, for that would determine the total cost over its operational lifetime and its cost-effectiveness.

EXPERIMENT REQUIREMENTS

Ask anyone involved in early Space Station studies about users' needs and the words "Blue Book" are sure to be mentioned. This was the name given to a hypothetical experiment program that was defined in order to establish performance and operational requirements for the Space Station. NASA Headquarters offices in various scientific, applications, and research disciplines were first asked to prepare lists of experiments which would be desirable and could be accomplished using a manned Space Station. These initial ideas were then expanded, further defined, and strengthened through the use of established groups of government, industry, and university scientists, through studies at the various NASA centers, and through industrial contracts.

Each experiment was examined to see whether it met criteria of scientific value, timeliness, professional and funding support, and whether it was enhanced by the presence of man. A series of "bedsheets"—large layout plans for experiments—was developed, and then detailed reports were prepared defining all the resources required to conduct each experiment. These requirements were then summarized to develop overall requirements for the Space Station, such as power, g-level constraints, heat rejection, data handling and transmission requirements, sample-return capabilities, manned manipulations, stabilization and pointing, and weights and volume. Groupings of the projected experiments were used to define subsets of requirements for experiment modules which could be operated in conjunction with the station in either a free-flying or attached mode.

There were many arguments about the validity of this approach to defining Space Station requirements. Were the proposed experiments real? Was there support for the development of such a wide variety of experimental activity? Could many of the objectives be achieved instead with unmanned free-flying satellites? Nevertheless, the approach described here appeared to be the only reasonable one that could be taken. Many of the proposed experiments followed up experiments which had been conducted in Apollo or were scheduled for Skylab missions. Others resulted from the creative minds of scientists who had been involved in those programs. Still other proposals were generated as precursors to operational instruments which ultimately would be more suitable in automated observation satellites. Most important from the viewpoint of those trying to define a Space Station program, this approach provided a set of specifications that was better than nothing and had the added advantage of developing a set of constituent users who would support Space Station development and who would be ready to use it, should it be approved.

SHUTTLE DESIGN CONCEPT

While the Space Station and experiment concepts were being developed, the Space Shuttle program was also making significant progress. Extensive NASA in-house, industry, and international study teams were examining alternatives not just for technical approaches but also for potential international participation in its development.

The most significant change during this period was the evolution from an all-reusable concept for the Shuttle to one employing a parallel burn or stage-and-a-half to orbit. The extensive development cost for a fully reusable, two-stage system and its accompanying low operational cost was weighed against the much lower development cost of the expendable tank reusable solid-rocket booster system and its higher operational cost. In the final analysis, the approach of simultaneously developing two hypersonic vehicles lost out to the booster-orbiter approach. The development of very high pressure throttleable cryogenic engines and utilization of reusable tiles for thermal protection were gambles that eventually paid great dividends for the Shuttle, although not without many years of developmental problems.

Meanwhile, the study teams in Europe continued to ask whether there was a role for Europe in the development of the Shuttle. Consideration was given to the development of components, such as the elevon, tail assembly, landing gear, nose cap, or cargo bay doors, and at least one proposal called for assembly of one complete Orbiter in Europe. However, all this came to naught. Too much was riding on the Shuttle, and, therefore, it would be a completely U.S.-developed system.

EXPERIMENT MODULE CONCEPTS

From the beginning, it was recognized that a Space Station had to provide a living environment for its crew and a central engine room of support systems for its overall operation. Because of the diverse needs of various user disciplines, however, some experiment groupings would be amenable to different modes of operation. It was also considered advantageous to decouple, as much as possible, experiment development from Space Station development. Thus, attached experiment modules could be brought to the vicinity of the Space Station, docked to it for an operational period, and then returned to the ground for upgrading of instruments or major repairs. Other, free-flying modules would be best suited for astronomical observations in which the normal disturbances about the Station by manned movements and station-keeping maneuvers would be disruptive to the astronomy objectives. In this case the module would be docked to the Space Station only periodically for minor adjustments, film replacement, or repairs and would, for the most part, operate station-keeping in an unmanned mode some distance away from the mother Station (fig. 15).

Early in the Space Station studies, the General Electric Company designed an Earth resources attached module and built a full-scale mockup to demonstrate its concept. In a similar fashion, the Martin Marietta Corporation designed a free-flying telescope module and built a full-scale mockup of its concept. Both efforts were a part of the Phase B Space Station studies which included development of a series of common modules to support the broad program of experiments from the so-called Blue Book. Experiments to be supported ran the gamut of disciplines from astronomy to space physics, space biology, Earth applications, biomedicine, and technology.

In addition to the experiment module concepts developed by the Phase B contractors, the Convair Division of General Dynamics conducted a series of studies on experiment modules which resulted in a family of attached labs and free-flying observatories using many common elements. This study effort was directed by Max Nein and Gene Oliver of Marshall Space Flight Center. One of the final tasks con-

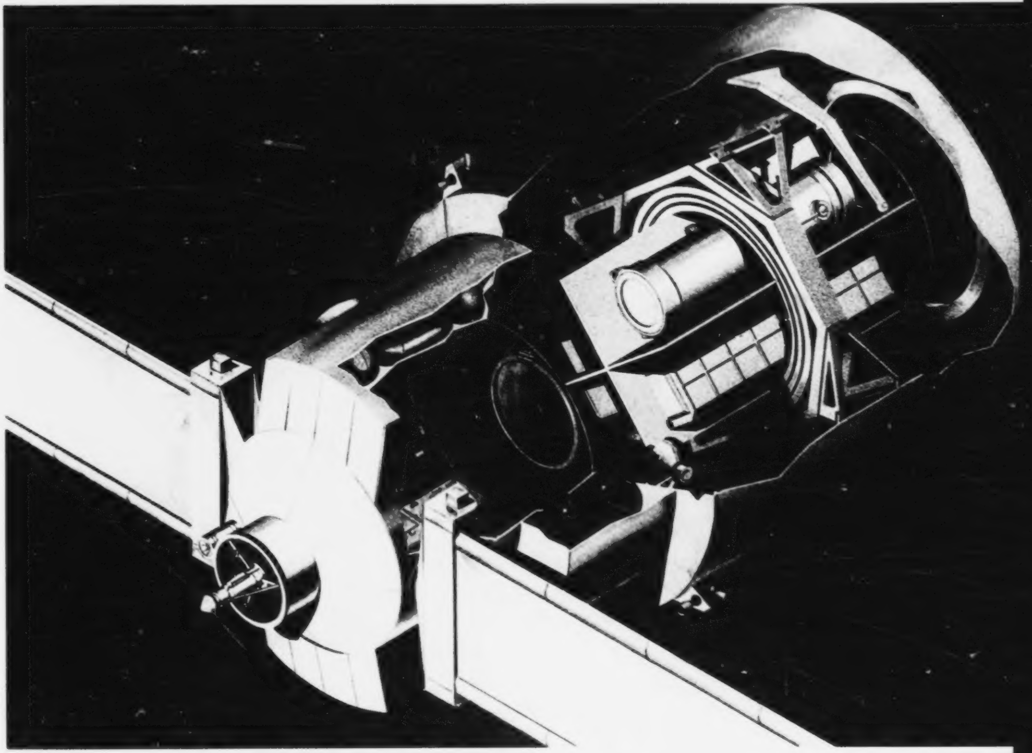


Figure 15. Marshall Space Flight Center's concept of a free-flying astronomy module which could be docked to a Space Station for periodic maintenance.

ducted in this contract was to examine the feasibility of operating from the Space Shuttle in the absence of a Space Station and to assess the impact of this mission mode on the proposed experiment program. This was probably the first look at what was to become the Spacelab concept. The study concluded that most of the experiment program could be accomplished in a Shuttle-only mode, although, to be more cost-effective, a 30-day Shuttle mission was desirable.

It is important to mention a related contract, directed by Tom Hagler of the Advanced Missions Office of NASA Headquarters and David Cramblit of MSFC and conducted by McDonnell Douglas Astronautics Corporation, called the Shuttle orbital application/requirements (SOAR) study. This study was very broad, aimed at a better understanding of how all types of payloads would interface with the Shuttle. Thus it addressed manned modules, pallets, satellites, and upper stages. The SOAR study provided significant imputs to the evolution of experiment module concepts and the eventual selection of the Spacelab approach.

RESEARCH AND APPLICATIONS MODULES STUDY

From May 1971 until August 1972, the Convair Division of General Dynamics conducted a Phase B study of experiment modules under the direction of Rod Johnson of my Headquarters team and Lowell Zoller of MSFC. In this effort the modules were renamed research and applications modules (RAMS), and equal emphasis was placed on sortie missions and on Space Station applications (fig. 16). It was conceived that any RAM element built for the sortie purpose could later be modified or adapted to provide Space Station support. Of course, the connotation of Phase B reflected the strong funding support and the further level of detail that could be achieved in the study.

Looking back on the RAM study, it is difficult to understand how NASA decided to proceed with a Phase B study of these experiment modules when the Space Station studies had been terminated and it would seem that the hope of an early start to the Space Station had been destroyed. The evolutionary approach of having modules which could first operate for short periods from within the Shuttle and later be serviced by a Station would appear to be the only defense.

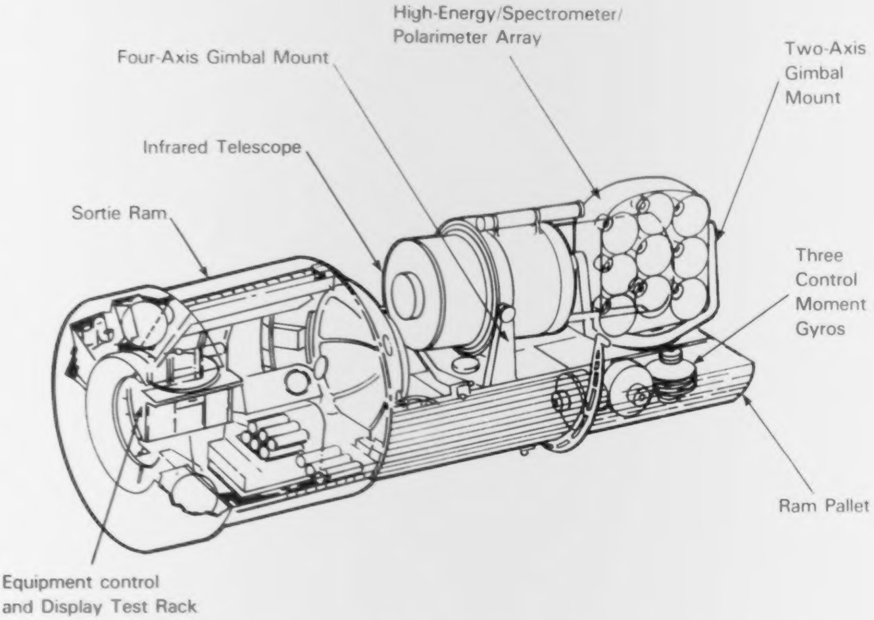

High-Energy/Spectrometer/
Polarimeter Array
Four-Axis Gimbal Mount
Two-Axis Gimbal Mount
Infrared Telescope
Sortie Ram
Three Control Moment Gyros
Ram Pallet
Equipment control and Display Test Rack

Figure 16. General Dynamics/Convair design of a sortie mission research and applications module (RAM) and pallet.

In any case, Convair, with its support team of North American Rockwell, TRW, and Bendix, and ERNO, MBB, and SAAB-SCANIA from Europe, produced a substantial study report with module and pallet concepts, free-flyers, and program plans and costs for a 15-year program. By this time, however, discussions between Europe and the United States had proceeded to the point where there was no further need for a NASA go-ahead for research and applications modules, and the Convair effort was terminated. Fortunately, Wally Withee, the Convair study director, had involved European contractors to a significant degree in the Phase B effort and had provided extensive reviews of the total effort within Europe, which had an important impact on the European decision process and on the transfer of information to the eventual European Spacelab team.

SORTIE CAN STUDY

Perhaps the most important study during this time period insofar as its effect on the development of the Spacelab concept was the Sortie Can conceptual design effort conducted by the Preliminary Design Office of Marshall Space Flight Center. From September 1971 until January 1972, a small in-house team explored the feasibility of this low-cost system devoted solely to the accomplishment of short-duration Shuttle missions with a manned laboratory in its cargo bay. Drawing on inputs from the industrial RAM and SOAR studies, a Sortie Can concept was defined to accomplish a wide spectrum of experimental objectives. The very name, Sortie Can, was chosen to emphasize the short-term nature of its mission and the low cost of the approach. Other study guidelines emphasized the use of existing subsystems, relaxed specifications, simple interface with the Shuttle, and easy access for experimenters similar to operations then being conducted by the Airborne Science Office of Ames Research Center using the Convair 990 airplane and Lear jet.

For the "can" itself, the study team concluded that a cylindrical module 15 feet in diameter and 25 feet in length was required. It also recommended a shorter module 15 feet long for some missions. As an accessory to the module, the team recommended an open truss pallet of varying lengths for mounting experiments outside the pressurized volume. The Sortie Can would also provide internal rack mounting for experiments, a work bench, observation and optical windows, an experiment airlock, a boom for the deployment of experiments, and an instrument pointing system for astronomy instruments (fig. 17). It is significant to note that on today's Spacelab missions, all these capabilities have been provided.

Where the Sortie Can differed from what was eventually developed was in the subsystem approaches. The study team envisioned an almost autonomous system in terms of power, thermal heat rejection, environmental control and life support, and data management and display. As we shall see in later chapters, the Spacelab became parasitic to the Shuttle, to some degree, in all these areas. In addition to

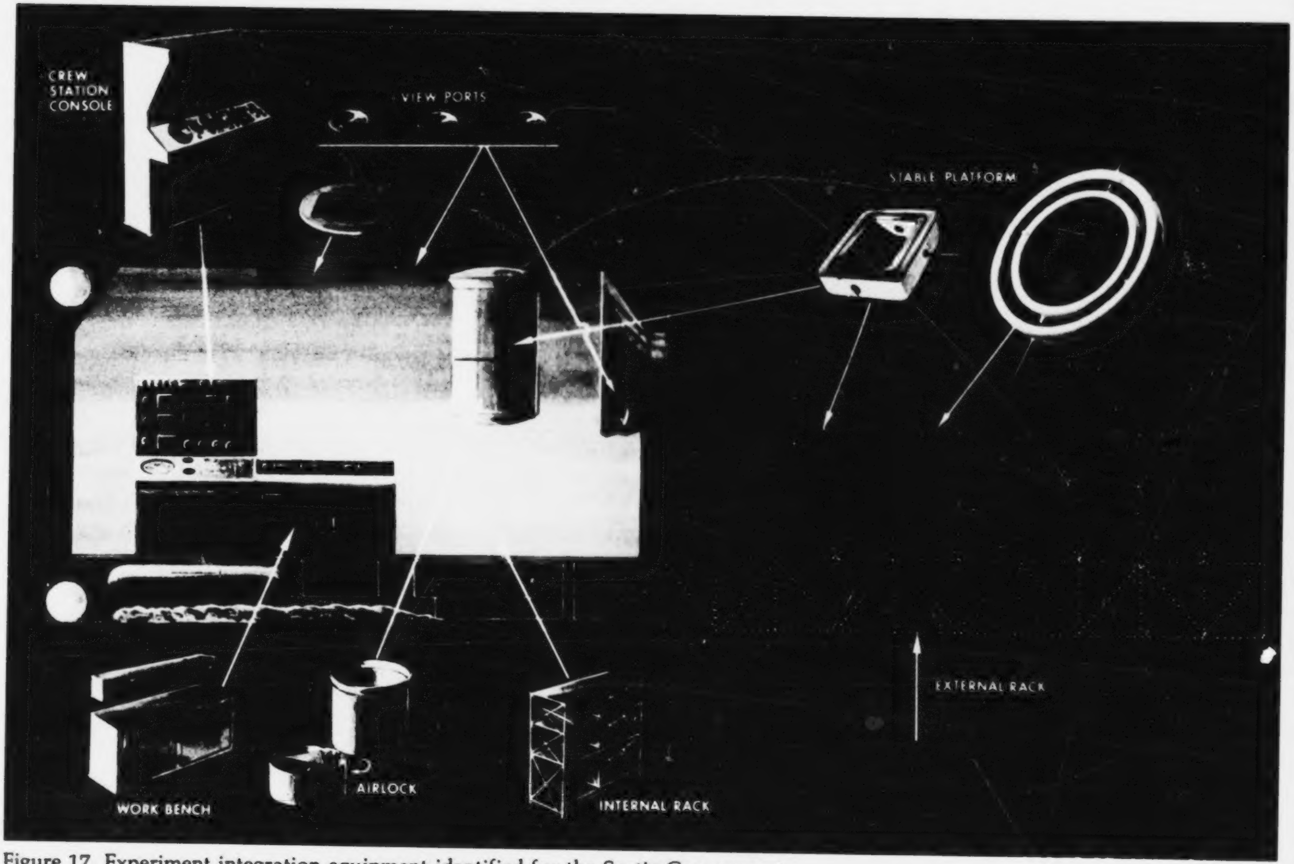

CREW STATION CONSOLE
VIEW PORTS
STABLE PLATFORM
EXTERNAL RACK
WORK BENCH
AIRLOCK
INTERNAL RACK

Figure 17. Experiment integration equipment identified for the Sortie Can concept.

these differences, the data management system eventually became much more sophisticated and capable than originally envisioned.

Pleased with the results of the Sortie Can conceptual study, Dale Myers, the Associate Administrator for Manned Space Flight, authorized Marshall Space Flight Center to continue in-house studies and planning for the definition phase of a Sortie Can project. By March 1972 a preliminary project plan outlined an inhouse approach to the development of a Sortie Can system. It proposed a 1-year definition phase followed by 5 years of design and development, culminating in a first manned orbital flight of the Sortie Can in 1978. Funding requirements for the total program were estimated at $90–115 million in 1972 dollars excluding the costs of in-house manpower and support contractors, which would be covered by the institutional base. Major structural subassemblies were to be fabricated in-house, whereas many components would be obtained by outside procurement. Every effort would be made to maximize the use of in-house resources whenever possible. Some might say this was a minimum-cost government buy-in proposal. Any modifications to this approach would result in substantial cost increases.

SORTIE CAN PAYLOAD PLANNING

During the Sortie Can study, the starting point for payload planning was again the volumes of experiment descriptions and requirements developed in the evolutionary Blue Book. Science groups and industrial studies continued to redefine these concepts in greater depth through the years. In addition, the first attempts at a Shuttle manifest were emerging, and so the study team examined these proposed early missions to determine whether the Sortie Can could play a significant role. They also examined whether a Sortie Can could carry the development flight instrumentation for the Shuttle test flights and whether it could provide a service platform for attending to the needs of orbiting satellites such as a large space telescope.

The primary result of Sortie Can payload planning was to establish a target set of performance specifications for the design and the support equipment that "typical" experiments would require. Target goals were established for electrical power and energy, weight and volume, contamination and temperature limits, stability and gravity levels, data and communications rates, and crew involvement. The study also provided some early mission analysis, considering questions of orbital altitudes and inclinations, delta-V requirements, timelining, and Earth-observation opportunities. The study concluded that the strongest contenders for early Sortie Can missions would be an infrared astronomy mission and a combined materials science and Earth-observation mission.

ESRO STUDIES

Because of European interest in the possibilities of post-Apollo cooperation and in response to NASA's overtures, studies were also under way during this time period under the auspices of the European Space Research Organization (ESRO). In 1971 a broad spectrum of exploratory studies were contracted to European industry in the following areas:

MATRA (France)	Comparative study of a scientific satellite to be launched by a Shuttle as opposed to the Thor Delta and study of a telecommunications satellite to be placed in synchronous orbit by a Shuttle and Tug.
MBB (West Germany)	Cost study of a biological research module to be attached to a Space Station.
HSD (U.K.)	Cost evaluation of a free-flying astronomy module (fig. 18).
BAC (U.K.)	Parametric cost analysis of research and applications modules.
HSD (U.K.)	Study of an advanced telecommunications station.
GETS (Belgium)	European technological capability survey.
BERTIN (France)	Study on use of space facilities for research and advanced technology.
Thomson-CSF (France)	Cost evaluation of a cosmic ray facility.

These studies were short-duration, low-cost efforts. Their specific conclusions and validity therefore are probably less significant than the breadth of projects addressed. It is fairly obvious that, at this point in time, the horizons were unlimited as far as European interests were concerned. It should also be noted that during this same time, ESRO's sister agency, the European Launcher Development Organization (ELDO), was conducting extensive studies of Shuttle elements and Space Tug systems as possible cooperative programs with NASA.

By 1972 the ESRO study effort had become much more focused on the Sortie Can concept, or as it was known more politely in European parlance, the Sortie Laboratory, Space Laboratory, or Space Lab. In particular, three European aerospace industry consortia, COSMOS, STAR, and MESH, had each been given a Phase A study to develop their own concepts (see fig. 9).

The COSMOS team was led by Messerschmitt Boelkow-Blohm (MBB) of West Germany and included SNIAS (France), MSDS (England), Selenia (Italy), ETCA (Belgium), CASA (Spain), and CIR (Switzerland). The COSMOS concept envisioned a module with two principal elements: a common support system and an integrated payload system (fig. 19). The common support system contained all the subsystems in one end of a cylindrical module shell. The integrated payload system consisted of experiment mounting racks cantilevered from the other end cone of the module. When the two elements were assembled, they provided an enclosed canister for the conduct of experiments in a pressurized environment. When disassembled, easy access to the experiments and their auxiliary equipment was provided.

The STAR team was led by the British Aircraft Corporation (BAC) and included Contraves (Switzerland), Dornier System (West Germany), Thomson-CSF

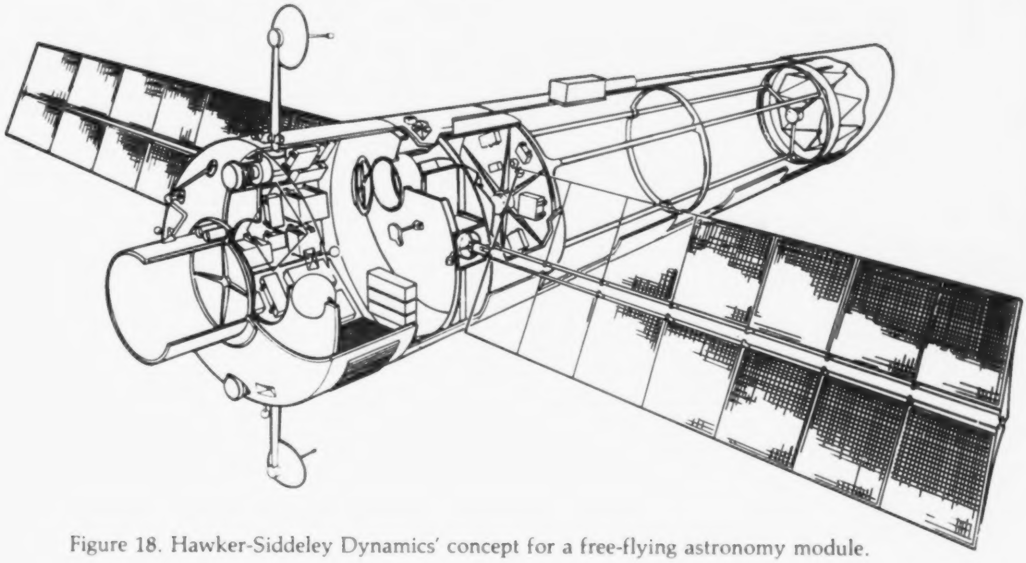


Figure 18. Hawker-Siddeley Dynamics' concept for a free-flying astronomy module.

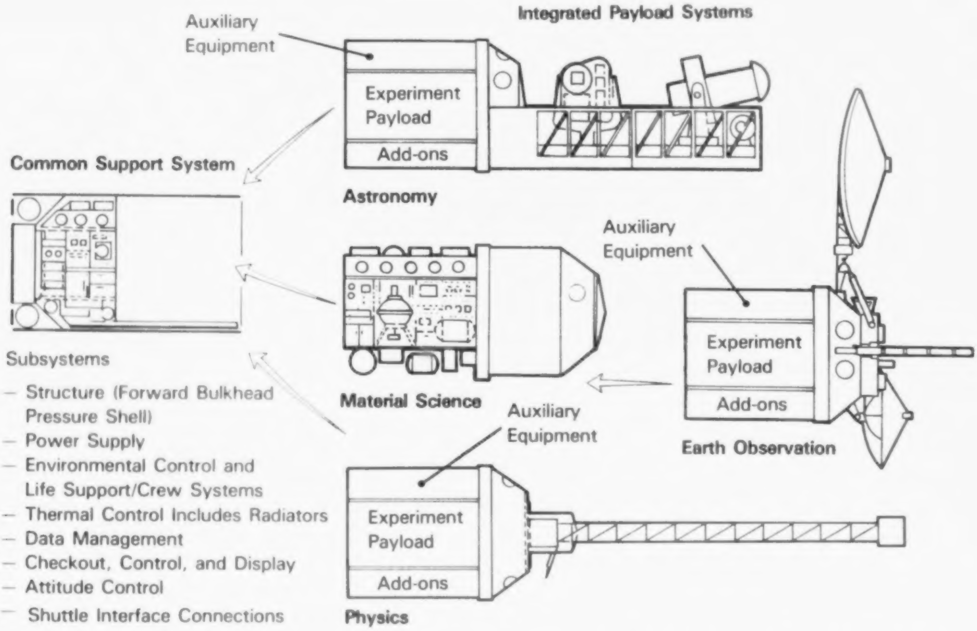

Auxiliary Equipment
Integrated Payload Systems
Experiment Payload
Add-ons
Common Support System
Astronomy
Auxiliary Equipment
Subsystems
— Structure (Forward Bulkhead Pressure Shell)
— Power Supply
— Environmental Control and Life Support/Crew Systems
— Thermal Control Includes Radiators
— Data Management
— Checkout, Control, and Display
— Attitude Control
— Shuttle Interface Connections
Material Science
Auxiliary Equipment
Experiment Payload
Add-ons
Earth Observation
Experiment Payload
Add-ons
Physics

Figure 19. The COSMOS team's concept for a common support system and an integrated payload system.

(France), CGE-FIAR (Italy), and Montedel (Italy). Its concept envisioned two common structure modules to permit flying either a module 7 meters long or a double module twice that length.

The third team, MESH, was led by the ERNO Division (West Germany) of the VFW-Fokker Corporation and included Battelle (Switzerland), BTM (Belgium), FIAT (Italy), HSD (England), INTA (Spain), MATRA (France), and Philips (the Netherlands). Key to the MESH group's proposal was a modular approach, in which extensions to the basic module at its largest diameter provided considerable flexibility for various scientific disciplines.

Each study team proposed a modularized pallet, which would provide a mounting table for instruments that needed to be exposed to the vacuum of space, but which could be controlled from within the module or from within the Shuttle itself. Perhaps the most surprising feature of the Phase A studies was that each contractor team was asked to compare the three conceptual approaches and make recommendations for the next phase of the program definition. Not surprisingly, each team supported its own concept as the best. In any case, ESRO had by this time decided to move into a Phase B system definition study effort.

PHASE B STUDIES

By the end of 1972, it was becoming fairly certain that Europe would make a commitment to build the Sortie Laboratory. Nevertheless, NASA was reluctant to count on a European commitment until signatures were on the dotted line. Therefore, in-house work continued at Marshall for the next year to define the Sortie Can concept in greater detail. At the conclusion of this effort, the results were turned over to ESRO for its use.

In the meantime, ESRO embarked on an aggressive effort of Phase B studies with European industry. Phase B1 was a short-lived effort by the three consortia that had performed the Phase A studies. At this point, the STAR team was dropped and Phase B2/B3 studies continued with teams led by MBB and ERNO through 1973 (fig. 20). There is little doubt that the decision to drop the STAR team was strongly political, since by this time it was clear that West Germany was the primary supporter of the push toward a Spacelab decision and would provide the majority of the financial support. Therefore, a German prime contractor was a necessity. Other recompositions of the teams reflected this strong push toward German leadership. The ERNO team for Phase B2, for example, now included AEG (West Germany), Aeritalia (Italy), BTM (Belgium), Dornier System (West Germany), Fokker (the Netherlands), HSD (England), INTA (Spain), MATRA (France), SABCA (Belgium), SEL (Germany), SENER (Spain), and Thomson-CSF (France). This was very close to the eventual team ERNO used during Spacelab development.

From a conceptual standpoint, ERNO's Phase B study reflects the final maturation of the basic Spacelab concept (fig. 21). The modular Spacelab concept allowed

Figure 20. Seated in the front row at the ESRO Phase B2 study review, June 28, 1973, at Noordwijk, The Netherlands, are (left to right) ESTEC Director Hammerstroem and NASA Directors Arnold Frutkin, Douglas Lord, and Dale Myers.

for experiments to be placed in either a pressurized module or on an unpressurized pallet. The length of either the module or the pallet could be adjusted by changing the number of modular elements. This feature permits changing the ratio of internal to external volume and allows the basic Spacelab weight to be adjusted to suit specific orbit altitude and inclination requirements. The basic modular elements of both the module and pallet were to be 3 meters in length, with either one or two segments used in the module and up to five segments of the pallet used in a pallet-only mission. Thus the concept was conceived, and so it was to be developed.

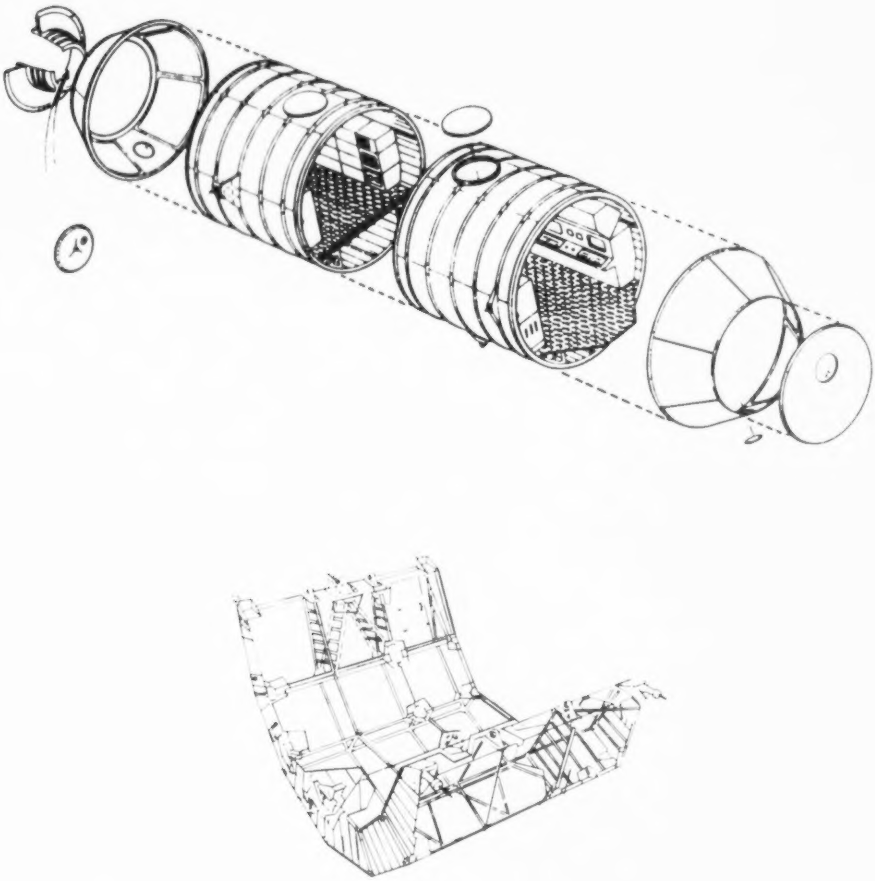


Figure 21. Phase B2 concept for the Spacelab module and pallet presented by ERNO in July 1973. At top, the major features of the Spacelab subsystems are shown; below, a view of the pallet.

Personal Reflections

The 1960s were a time of significant personal change for me. In 1960 I left my enjoyable and comfortable career in aerodynamic research at Langley Research Center for a 2-year stint as a Technical Assistant to the President's Science Advisor. This choice assignment on the White House staff was a challenging and rewarding experience. It was during this time that the change from the Eisenhower to the Kennedy administrations occurred, Yuri Gagarin and Alan Shepard made their historic space flights, and the Apollo lunar-landing decision was made. It was my good fortune to attend some of the important meetings of this period, to participate in the many space studies made by technical panels of the President's Science Advisory Committee, and to develop a close working relationship with the NASA Headquarters staff as I monitored the various space activities of that time. It followed naturally for me to turn to NASA Headquarters for my next assignment, where, from 1962 until 1972, I received a variety of assignments within the Office of Manned Space Flight, all related to planning advanced manned missions.

The tight control of advanced mission studies during the 1960s is still a strong memory for me. After several unfortunate instances where an overly enthusiastic NASA employee or aerospace industry employee would talk to a member of the news media about some future project, giving the impression that NASA was off and running in a new direction, not yet approved by either the Administration or the Congress, tight clamps were put on all future studies. In particular, the NASA Associate Administrator at that time, Dr. Robert C. Seamans, caught the brunt of the criticisms and became the controller of such studies. Each year the various program offices at Headquarters would have to report to Seamans on the accomplishments of the previous year's studies and defend their proposed studies for the next year. Nevertheless, it was possible to obtain approval and carry out a large number of very diverse studies.

Technology efforts in support of future missions also covered a gamut of objectives during those years. A Space Station prototype program was pursued for many years by the Manned Spacecraft Center to demonstrate the feasibility of closed loop life support systems. The problems with the commode during the early flights of the Shuttle were no surprise to me because of the difficulties that were encountered 20 years earlier in demonstrating the effectiveness of breadboard waste disposal systems. Similar technology efforts were expended in ground testing lightweight, deployable solar arrays, one outgrowth of which was demonstrated in the September 1984 Shuttle flight.

A more unusual technology effort was the Kiwi program, aimed at demonstration of a nuclear reactor which could heat hydrogen to very high temperatures as the predecessor to a nuclear-powered upper stage. I recall witnessing a test of a Kiwi reactor at the Jackass Flats test area in Nevada. The test was all ready to begin when the propane torch, which was intended to ignite the exhaust hydrogen, refused to cooperate and self-extinguished. The tests were delayed for several hours until the area could be made safe and the torch reignited. By that time, many of the important congressional observers had long since left to attend a West Coast convention.

The studies of possible manned missions to Mars and Venus were of particular interest to me because of the unusual challenge posed by the orbital mechanics of the missions. These missions would have to be of very long duration, and many studies were conducted to find the best departure time from Earth, optimum stay time at the target planet, and most efficient return trajectory. In some time periods, it could be proved that a mission to both Mars and Venus could be accomplished in less time than a mission to only one of the planets. One of the enthusiasts on my staff, frustrated with NASA's foot-dragging in this area, volunteered to make a one-way trip to Mars with the idea of staying there until the technology could be developed to bring him back. Needless to say, his offer was never seriously considered.

The idea of a lunar base was also of special interest. In fact, NASA obtained several outstanding U.S. Army officers with experience in the building of Camp Century, a nuclear-powered base beneath the Greenland ice cap, to direct the studies of such bases on the Moon. The analogy between an Antarctic base and one on the Moon was not missed either, as a number of NASA representatives (including Wernher von Braun) traveled to McMurdo Sound and the South Pole to observe the lessons learned there.

When attention turned to the Space Station in the late 1960s, Chuck Mathews played a key role in establishing a new type of management approach. From his experience as Project Manager for the Gemini program at the Manned Spacecraft Center (MSC), he leaned strongly toward an organization in which the field centers would have a major role in managing the Space Station effort. A central technical team as part of the Headquarters organization was set up at MSC to be headed by Frank Borman, Commander of the very daring and spectacularly successful *Apollo 8* mission. His office was assigned three key representatives from MSFC (Frank Williams), MSC (Jack Small), and Langley (Bill Hayes). Although Mathews headed a Task Force Office at NASA Headquarters with me as his deputy, it was anticipated that Borman's office would head the oversight and technical implementation of the Space Station development. Unfortunately, during the time that this organization was in existence, Borman spent so much of his time on special White House assignments that this concept never got a fair trial.

Another indication of the importance of the Space Station Phase B studies was that the Source Evaluation Board had on its membership the Deputy Directors from MSC, KSC, and MSFC. This board, conducted out of NASA Headquarters and chaired by Mathews, took its job very seriously, and the entire operation was closeted in a new office building in Arlington, Virginia for the duration of the evaluation process.

Once the Phase B studies of the Space Station were under way, the competition between MSFC and MSC and their respective contractors (McDonnell Douglas and North American Rockwell) began in earnest. After the first year of Space Station Task Force operation, I was promoted to Director and enjoyed leading the NASA and industry team that examined in some detail the various Space Station concepts. At the study reviews, each team would attempt to outshine the other. When North American unveiled its very fine mockup at Seal Beach, it was obvious that McDonnell Douglas had been scooped. Not only McDonnell Douglas, but my boss, Dale Myers, got a rude shock when he heard about this mockup while defending Skylab needs during congressional testimony. Nevertheless, both recovered, and soon MSFC/McDonnell Douglas had built a mockup that was equal, if not better than, that of the MSC/North American Rockwell team (fig. 22). To me, the 33-foot-diameter mockups represented the highwater mark of the Space Station studies of this era. The later concept to assemble the station from Shuttle-sized modules never seemed as attractive. I felt that each module would become a crowded hallway and the modular concept would be akin to Earth-bound facilities assembled from mobile trailers. I simply liked the roominess and efficient layout of the Saturn V station.

NASA engaged in several mission simulations to lend credence to its design and operational concepts for Space Stations. The Tektite and Ben Franklin programs involved underwater activities to give a degree of isolation and scientific objective to the crew. In the case of Tektite, a crew remained 100 feet underwater in a habitat built by the General Electric Company, located off St. Johns in the Virgin Islands (fig. 23). This program was conducted in cooperation with the U.S. Navy and the Department of Interior. Later, several crews, including one of women, conducted a second series of missions in the Tektite habitat. The Ben Franklin submersible was built by the Grumman Corporation and included one NASA representative (Chet May from MSFC) in its crew as it drifted along the Gulf Stream. All these missions added knowledge applicable to Space Stations, particularly with respect to the interaction among the crew and between the crew and the support base.

In early 1970, I was given a leave of absence to attend the Federal Executive Institute at Charlottesville, Virginia, one of the management "charm schools" provided by the government. I returned all charged up to apply the management techniques I had learned to the emerging Shuttle and Space Station organizations at NASA Headquarters. Unfortunately, my counterpart in the Shuttle organization had not attended the same school, and so my ideas fell on deaf ears. In retrospect, it is too bad our offices did not establish a better working relationship, because the Shuttle/Spacelab interface problems dragged on for several years and never were solved successfully until an effective mechanism of interface control documentation was established and direct contacts effected between the Shuttle contractor, Rockwell, and the European Spacelab contractors.

Another relationship which has been difficult throughout the life of the manned spacecraft program and which continues to pose problems today is that between

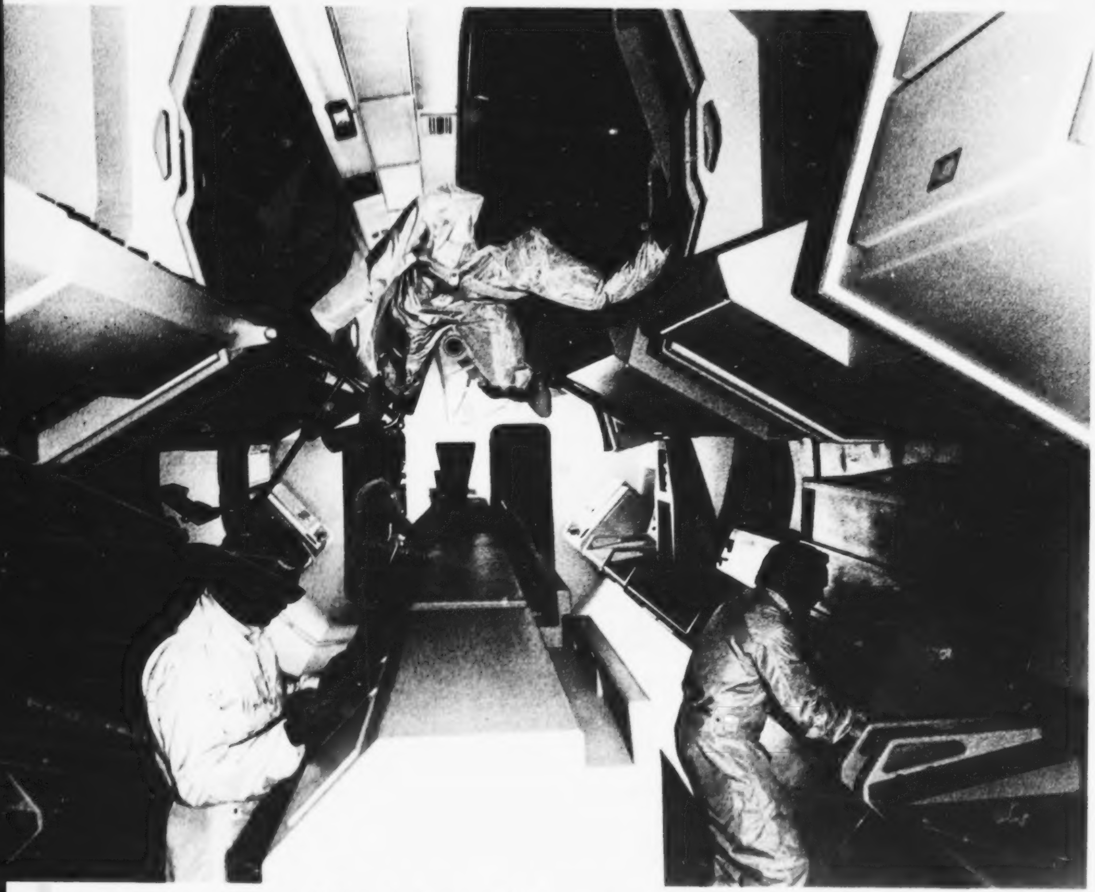


Figure 22. McDonnell Douglas mockup of a general purpose laboratory, part of its modular Space Station concept, December 1971.

scientists and the developers of the manned systems. A strong core of space scientists believes that the money spent on manned systems could be invested more wisely in automated systems. They ask, "Why take man's stomach into space, when what you want is only his eyes and ears?" When the Skylab missions proved to be so successful, I thought the value of man in space experimentation had been demonstrated to everybody's satisfaction, but such was not the case. At times in the Spacelab pro-

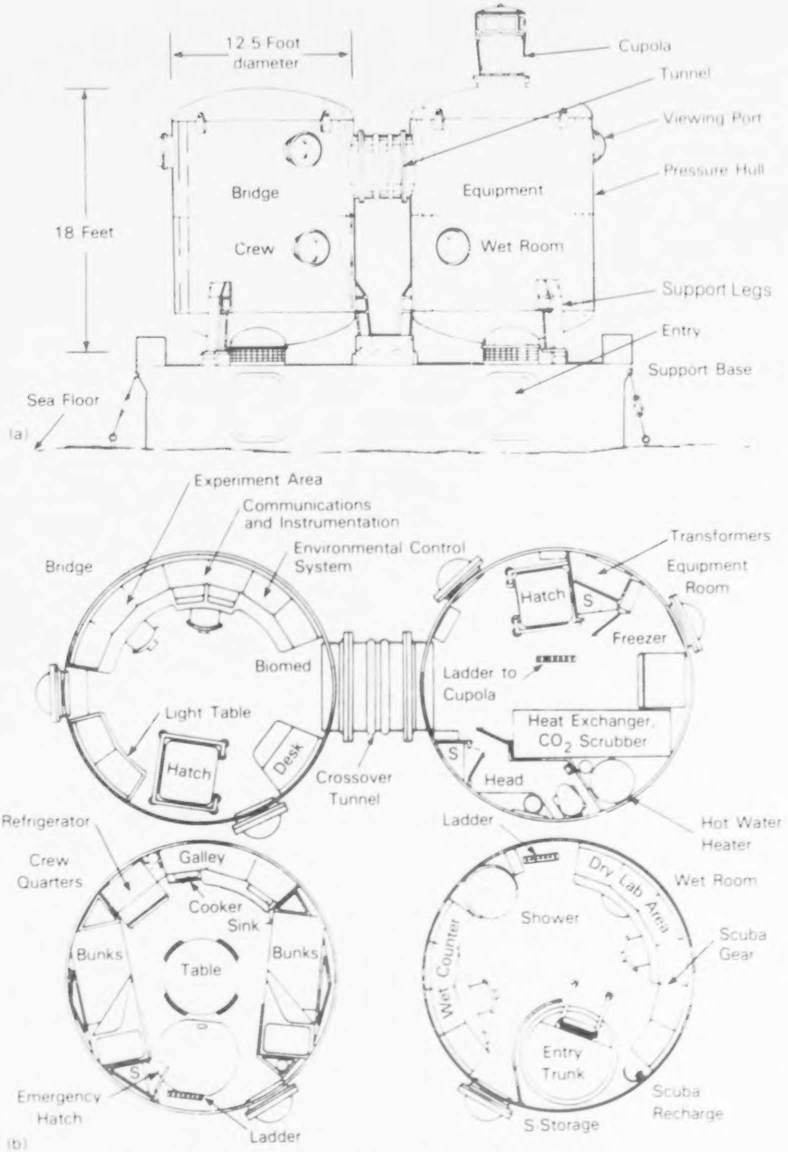

12.5 Foot diameter
Cupola
Tunnel
Viewing Port
Pressure Hull
18 Feet
Bridge
Crew
Equipment
Wet Room
Support Legs
Entry
Support Base
Sea Floor
(a)
Experiment Area
Communications and Instrumentation
Environmental Control System
Bridge
Biomed
Light Table
Hatch
Desk
Crossover Tunnel
Transformers
Equipment Room
Hatch
S
Freezer
Ladder to Cupola
Heat Exchanger, CO_2 Scrubber
S
Head
Hot Water Heater
Refrigerator
Crew Quarters
Galley
Cooker
Sink
Bunks
Table
Bunks
S
Emergency Hatch
Ladder
(b)
Ladder
Dry Lab Area
Wet Room
Shower
Wet Counter
Scuba Gear
Entry Trunk
Scuba Recharge
S-Storage

Figure 23. Layout of the Tektite underwater habitat. The side view is shown above; below, the plan views of the habitat compartments.

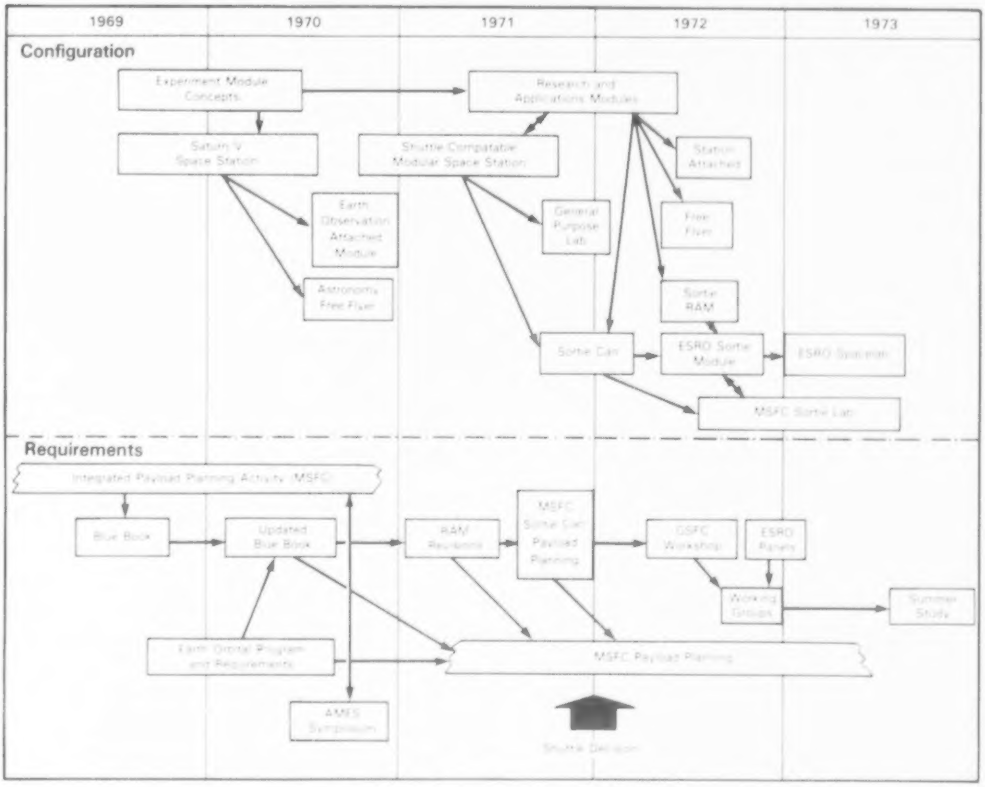
gram, it seemed that the scientists had to be pulled into the program "kicking and screaming." Fortunately, the Joint User Requirements Group became a very effective ombudsman for those scientists who did see value in a manned laboratory on the Shuttle. And as specific missions were approved for flight, the Investigator Working Groups, made up of Principal Investigators, became effective mechanisms for working out problems between the Spacelab systems and the experiments to be flown.

During 1971 I was assigned the interesting task of examining the technology transfer that might occur in a cooperative post-Apollo program with Europe. This task was apart from my normal Space Station responsibilities and required me to become familiar with the various ideas then being considered with respect to cooperation in the Space Shuttle or Space Tug programs. In addition to examining discrete technology that might be transferred in specific programs, I also contacted U.S. industry representatives to assess their attitudes about the effect of such transfers. By the time my investigation was completed it was evident that technology transfer would not be the driving factor in any post-Apollo decision, with the possible exception of the Space Tug where significant help might be needed in Europe. It was also apparent that much of the European interest in post-Apollo cooperation stemmed from the desire to gain program management and systems engineering experience in a program of this magnitude rather than in specific technical know-how or direct commercial benefit. By the time of the first Spacelab mission, many of the European participants had forgotten this original motivation.

The evolution of the name Spacelab was another interesting facet of the early program. The word "sortie," while it seemed to give the connotation of a short mission—out and back—that we desired, never received much support in Europe. Once we learned that in French it was a much-used word from the verb *sortir*—to leave—we began to understand their distaste. In fact, the French word "sortie" is equivalent to the English term "exit." Of course we knew that the word "can" could never survive as a formal name for the program; it was much too undignified. We hesitated at "Spacelab," however, because we knew there would be confusion with its contemporary program, Skylab. However, despite NASA's objections, once the Europeans had committed to the program they unilaterally decided to use the name Spacelab, and Spacelab it became.

Looking back on these formative years, the most difficult question to answer is, "Who invented the Spacelab concept?" Having given much thought to this question and after discussing the issue with many of those involved, I finally must come to the conclusion that it was not suddenly conceived as a light-bulb type of inspiration. Rather, it evolved over a period of months as the Space Station development effort gradually slipped from our fingers and everyone looked for ways to make the Shuttle capable of accomplishing many of the scientific objectives of the Space Station, until such time as the Station would finally receive a go-ahead (fig. 24). The U.S. contractors who studied the Space Station and experiment module concepts, the NASA field center teams who directed these studies and conducted in-house efforts of their own, and the NASA Headquarters groups that funded and guided these efforts all played a role in the development of the Spacelab concept. Although we sometimes described it as a "poor man's Space Station," Spacelab has turned out to be rich in capability, flexible in operation, and rewarding in international cooperation.

Figure 24. Evolution of the Spacelab concept and its payloads.


1969
1970
1971
1972
1973
Configuration
Experiment Module Concepts
Research and Applications Modules
Saturn V Space Station
Shuttle Compatable Modular Space Station
Station Attached
Earth Observation Attached Module
General Purpose Lab
Free Flyer
Astronomy Free Flyer
Sortie RAM
Sortie Can
ESRO Sortie Module
ESRO Spacelab
MSFC Sortie Lab
Requirements
Integrated Payload Planning Activity (MSFC)
Blue Book
Updated Blue Book
RAM Revisions
MSFC Sortie Can Payload Planning
GSFC Workshop
ESRO Panels
Working Groups
Summer Study
Earth Orbital Program and Requirements
MSFC Payload Planning
AMES Symposium
Shuttle Decision

3 Getting Under Way
1973 – 1974

EARLY REQUIREMENTS AND PLANS

NASA and ESA management recognized that coordination and information exchanges would be required at several levels within the program. Level 1 was established at the headquarters level and was represented by the heads of the program designated by ESRO (Jean-Pierre Causse) and NASA (me). The principal mechanism for discussions and decision making was the Joint Spacelab Working Group, which we co-chaired and which initially met bimonthly, alternating between a European and a U.S. site. As the program matured, this group met less frequently, although regular meetings of a more informal nature between the two Program Directors continued throughout the life of the development effort.

The more detailed technical coordination was accomplished at Level 2 and was overseen by the ESRO Project Manager at ESTEC (Heinz Stoewer) and the NASA Program Manager at MSFC (Jack Lee). In addition to being key members of the Joint Spacelab Working Group, they met regularly and established a mechanism for day-to-day flow of technical information between the two agencies. They also arranged and monitored exchanges at lower levels, including meetings and data transfer between industry participants on both sides of the ocean.

Prior to the consummation of the Memorandum of Understanding between ESRO and NASA, Joint Spacelab Working Group activities had focused on guidelines for the potential development effort, documents which might be required, changes in the Shuttle concept and its mission model, possible exchanges of liaison personnel, and the coordination of the respective Phase B study activities. Now that the program was a reality, the working group meetings took on a new sense of urgency. The minutes of the meetings during the next year are filled with sparring activities between representatives of ESRO and NASA as they attempted to identify concretely their respective responsibilities, schedules, plans, and detailed technical specifications for the Spacelab. What Shuttle resources would be used? Would the igloo (a pressurized canister to house the subsystems in a pallet-only mission) have a separate set of subsystems? What was the best diameter for the Spacelab, 14 ft or 12 ft? What were the user requirements? How do we market the Spacelab to prospective users? Should we conduct simulated Spacelab missions using the Ames Airborne Science Program as a prototype? What should be the constraints for the early Spacelab missions? What should NASA's role be in helping ESRO choose its prime contractor team? What computer should be selected for the data system? Should we have an Operations Working Group? Were the weights under control? Should there be an Interface Control Document with the Shuttle? The questions seemed endless, and, at times, unanswerable, but gradually answers were found.

One of the key functions performed during this time related to user requirements. Recognizing the need for inputs to overall Shuttle planning from potential users, Dr. John Naugle, chairman of the Shuttle Payload Planning Steering Group, had already established a Joint User Requirements Group (JURG), initially co-chaired by Dr. Gerald Sharp of NASA and Dr. Johannes Ortner of ESRO. The Spacelab Program Directors, recognizing the value of this group to their planning, invited its chairmen to become members of the Joint Spacelab Working Group. For the next several years, JURG was a valuable adjunct to the Spacelab program in melding the requirements from the scientific working groups sponsored by both agencies into a single set of requirements for the Spacelab. JURG co-chairmen, or their representatives, became third parties to the regular meetings of the Joint Spacelab Working Group. From the beginning, Spacelab planning was characterized by the desire to understand the needs of potential users and to build a system and operational concept that would be responsive to those needs.

Another element of the Joint Spacelab Working Group should not be ignored. At each meeting, the respective International Affairs Offices of NASA and ESRO were represented. These members were very careful to avoid meddling in the technical management of the program, but they contributed immeasurably to discussions of more politically oriented topics such as the interpretation of the agreements, assignment of liaison and support personnel, relationship to other programs, technology transfer, proprietary rights, and customs problems. For those of us technical managers who were diplomatic novices, the contribution of these experts with political know-how was essential to this cooperative international effort.

Two important personnel changes occurred within ESRO during the Spacelab program's first year. In early April 1974, J. P. Causse, ESRO Program Director, resigned to accept the prestigious position as Director of Research for the large French company Saint-Gobain-Pont-a-Mousson. There were conflicting reports as to the reason for his departure, but all agreed that a very strong and effective director had been lost to the program. His departure placed the ESRO Level 2 manager, Heinz Stoewer, in a very difficult position for the next several months, as he had to serve as both Project Manager and Program Director.

About the same time, Dr. Johannes Ortner resigned his scientific leadership role with ESRO to return to his native Austria to head the newly created Austrian Space

Agency. In characteristic fashion, Dr. Ortner jokingly remarked that he hoped to name the new organization the National Austrian Space Agency so it could be known as NASA. To replace Dr. Ortner in leading ESRO's efforts related to user participation, Jacques Collet was appointed as the new co-chairman of the Joint User Requirements Group. Collet was no stranger to the team; he had participated in ESRO activities since its early Space Station studies.

Another administrative facet of the program was to agree on an approach to European and U.S. teams visiting each other's sites. After much discussion, a procedure was established at the Joint Spacelab Working Group meeting on July 12, 1974. The first step was to exchange lists of personnel who were members of ESRO and NASA Spacelab program teams. Persons whose names appeared on these lists were considered to be accredited and arrangements for most visits could be handled between ESTEC and MSFC. Persons whose names did not appear on these lists had to be accredited by the International Affairs Offices of ESA or NASA Headquarters as the need arose. The key to any visit was to assure that the following offices were kept informed: the activity to be visited, the Headquarters Program Offices, the Project and Liaison Offices at ESTEC and MSFC, the International Affairs Offices, and the NASA European Representative in Paris. Visits on program level matters were handled by the Headquarters Spacelab Program Offices, as were approvals of large groups for major reviews or for extended durations. Although the procedure at first appeared cumbersome, once the lists were established and exchanged, routine visits were handled rather expeditiously. Nevertheless, one could always count on the fact that visits to certain sites (e.g., JSC) would prove to be frustrating to the European visitor. Somehow the approval never seemed to arrive before the visitor.

Strong teams continued to search for and analyze potential Shuttle payloads. Under the leadership of Harry Craft at Marshall Space Flight Center, the Shuttle System Payload Data Activity study developed descriptions for 44 payloads. Supporting studies were conducted by IBM on data management for the various scientific payloads and to develop computer software sizing requirements, in terms of memory capacity and processor speed, for 13 Spacelab sortie payloads. During this period, only dedicated Spacelab missions were being studied; the idea of mixed cargoes with satellites or deep-space payloads with upper stages had not yet been considered. In early 1974 MSFC conducted another study under the leadership of Craft, Carmine de Sanctis, and William Lide of six candidate Spacelab payloads recommended by the Joint User Requirements Group. These payloads were selected from the astronomy, solar physics, atmosphere and space physics, Earth observations, space processing, and life sciences disciplines. Underlying many of these study activities were detailed study efforts spanning a period of years, for example, Plasma Physics and Environmental Perturbation Laboratory, 1971-73; Atmosphere, Magnetosphere, and Plasma in Space, 1970-75; Reference Earth Orbital Research and Applications Investigations (Blue Book), 1970-71; Atmospheric Science Facility, 1973; Life Science Payload Definition Study, 1970-75; Biological Holding Facility Study, 1974-75; and Space Processing Applications Payloads Equipment Study, 1974. Folding the diverse requirements from these many studies into a reasonable set of specifications for the Spacelab was a Herculean task, and the many scientists and technicians both within and outside the NASA centers who contributed to this effort are too numerous to give them proper recognition.

Gradually, however, some order was established out of what had seemed to be complete chaos. The most significant early document in this regard was the Spacelab Design Requirements Document, which was developed by NASA, reviewed at the highest levels, and approved by Administrator Fletcher on September 7, 1973. To arrive at meaningful design requirements, certain design assumptions had to be made. The most significant of these was the existence of a Tracking and Data Relay Satellite System in the anticipated Spacelab mission time frame. This was assumed for planning purposes, although NASA had not yet committed to such a program. A three-man Shuttle Orbiter crew with one to four additional payload-oriented personnel, at least a 10-percent weight margin, and a 1-arc-second stabilized platform were also specified. It was established that the Orbiter would reject 8.5 kw. of payload heat and provide 7 kw. continuously and up to 12 kw. for peak loads of electrical power to the Spacelab. In addition, the Orbiter would provide coarse stabilization (± 0.5°), rescue and extravehicular (EVA) support, as well as communication with ground stations.

The Design Requirements Document was made available to ESRO in time for its kickoff meetings for the Phase B3 definition efforts. This document was intended to be short-lived with the requirements it contained to be incorporated into the Spacelab Level 1 Guidelines and Constraints Document and the Level 2 System Requirements Document. Those requirements related to the Shuttle would also have to be incorporated into the Shuttle Level 1 Program Requirements Document and the Level 2 System Payload Accommodations Document. By July and August 1974, two additional requirements documents had been prepared by the Joint User Requirements Group: the Spacelab Payload Computer and Display Requirements and the Instrument Pointing Subsystem Requirements.

Another area in which NASA took the early lead was in formulating the Guidelines for Developing Safety, Reliability, and Quality Assurance Requirements, which was provided to ESRO in March 1973. Recognizing that this would be Europe's first direct involvement in a manned spaceflight program and given the extensive experience which NASA possessed in this regard, the document represented a handbook for ESRO and its contractors in this new endeavor. Since the Spacelab would be operated as a part of the Space Transportation System, the ultimate responsibility of NASA for reliability, quality, and safety of the Spacelab was readily accepted by ESRO and was an area in which complete cooperation ensued from beginning to end of the program. The mutual respect and frank exchanges among Guy Cohen of the NASA Headquarters team and Carla Norton of the MSFC team with Lars Tedemann on the ESA side contributed significantly to the achievements in this critical area of the program.

In addition to all these efforts directly and indirectly aimed at getting the Spacelab program under way, an important NASA management study was initiated by a memo from Deputy Administrator George Low dated August 14, 1973. It requested the Associate Administrator for Manned Space Flight to establish a Shuttle payloads team to describe what had to be done, NASA-wide, on Shuttle payloads, to hear the views and philosophies extant in the agency as to how and by whom these things should be done, and to evaluate alternative ways in which these responsibilities might be distributed within the agency. For the next few months, the Shuttle Payload Activities Ad Hoc Team, chaired by Charles J. Donlan, Deputy Associate Administrator for Manned Space Flight (Technical), addressed these issues and presented its final report to Dr. Low, the Associate Administrators, and the center directors on April 17, 1974.

It should be remembered that, from its inception, Spacelab had been conceived as a program in which users would participate in the operational phase to a very strong degree and that the Spacelab would gradually be assembled from elements flowing in from user facilities around the world. The Donlan committee recognized the necessity for four levels of integration: Level IV, assembly of individual instruments and their unique supporting subsystems into a compatible package of equipment to accomplish specific mission objectives; Level III, integration of one or more instrument assemblies with Spacelab elements (module and/or pallet); Level II, assembly of Spacelab elements into a cargo for a single Shuttle flight; and Level I, integration into the Orbiter (fig. 25) The committee also recognized that some Spacelab missions could be dedicated to a single scientific discipline, whereas other missions would be multipurpose, and handling the various integration levels could be different in these cases. The idea of mixed cargoes (satellites or deep-space payloads with Spacelab elements) still was not addressed.

It had been assumed prior to the study that racks from the modules, and pallets, could be shipped to various user facilities for experiment installation, as desired. Marshall Space Flight Center planned to have complete capability for assembling the Spacelab payload and checking it out using a simulator to represent the Spacelab subsystems (now identified as Level III). Level II and Level I were to be accomplished routinely at the Kennedy launch site, although MSFC wanted to accomplish Level II activities at its home site during some of the early Spacelab missions.

In addressing the issue of Shuttle and Spacelab utilization, the Donlan committee recognized the need for a customer focal point within NASA and recommended establishing such an office at Headquarters with supporting teams at MSFC in payload planning and at JSC in flight planning and mission assignments. A Headquarters organization was established within the Office of Manned Space Flight and, under the direction of Chester Lee, has provided a strong customer center within NASA for potential users of the Space Transportation System. In addition to scheduling missions, it has been the responsible organization for negotiating launch agreements and for establishing utilization policies. In a supporting role the Payload Planning Office at MSFC was created under O. C. Jean and the Shuttle Payload Integration and Development Program Office was formed at JSC under Dr. Glynn Lunney.

In addition to recommendations on payload initiation, mission and flight planning, and center assignments, the Donlan committee made 10 specific recommenda-

	Ground Operations Integration Levels				Orbital Operations		
Type of Spacelab	Level IV	Level III	Level II	Level I	Shuttle	Support Module	Payload
Dedicated Spacelab	Customer*	Customer*	Customer at KSC KSC	KSC	JSC	Customer JSC Data, customer Resources, JSC	Customer*
Multi-purpose Spacelab	Customer*	MSFC as Customer Agent	MSFC MSFC at KSC KSC	KSC	JSC	MSFC as Customer Agent JSC Data, MSFC Resources, JSC	MSFC as Customer Agent

* Customer could use MSFC, JSC, or other center facilities.

Figure 25. Levels of integration for Spacelab as identified by the Donlan committee in 1974.

tions with respect to Spacelab ground and flight operations. The first was to reassess the cost-effectiveness of having the subsystem module processed (i.e., Level II) through MSFC for the early Spacelab missions as then envisioned. Shortly thereafter, when John Yardley replaced Dale Myers as Associate Administrator for Manned Space Flight, he decided that all Level III and II integration should be done at the Kennedy Space Center. Reflecting on this decision, Yardley stated that his principal concern with Level III at MSFC was that it would "institutionalize" the Spacelab at Marshall; i.e., it would require an excessive amount of manpower and would duplicate capability which would be necessary to have at KSC in any case.

The second recommendation was to design the Spacelab so as to separate resources management and payload data management. Although JSC later challenged this autonomous approach to Spacelab data management, it eventually capitulated and a reasonable separation approach was attained. This was accomplished by providing control of the Spacelab subsystems from the Orbiter aft flight deck where a career astronaut (Mission Specialist) provided the resources management, while the Payload Specialists controlled their payload data from the Spacelab.

Recommendations 3, 4, and 5 were to give MSFC responsibility for configuration management, for multipurpose Spacelab integration, and for payload flight control of multipurpose Spacelab flights. Recommendations 6 and 7 were to give KSC responsibility for subsystem module maintenance and for integration of the subsystem module to other Spacelab elements. Again, these recommendations were generally accepted.

The eighth recommendation was that dedicated experiment modules, racks, and pallets should be assigned to payload centers. The decision to focus Level III at KSC negated the idea of shipping experiment modules to payload centers. However, both racks and pallets have been assigned to remote payload centers, although to a lesser degree than was originally anticipated. A subsequent management decision to focus Level IV integration at KSC, also, has made this recommendation the most neglected one of the study.

The ninth recommendation was to assign to JSC the responsibility for flight operations control of the subsystems management. The system set up to perform Spacelab subsystem control from the aft flight deck automatically put JSC, as the Shuttle operator, in control of Spacelab subsystems during the mission.

Finally, the committee recommended that a lead center be designated for dedicated Spacelab missions involving several centers. This is, of course, only good management and is the procedure being followed. Taken in context, one would have to say that the Spacelab recommendations of the Donlan committee were very perceptive and, for the most part, were implemented in the program.

BOTH SIDES ORGANIZE

When the European Space Conference made its Spacelab commitment in December 1972, there was no resident NASA Representative in Europe. Although earlier there had been a series of NASA European Representatives located in the American embassy in Paris to coordinate activities between NASA and various European organizations, the position was left vacant from mid-1972, perhaps as a bit of an irritant in view of the long delay in obtaining a formal European commitment on the post-Apollo program. Now, with the commitment made, the wheels began turning again and W. P. (Pat) Murphy, Jr., took up the post of NASA European Representative. Murphy, a retired Navy Captain and former member of the KSC staff, arrived in Paris in March 1973 to monitor all NASA activities in Europe, including Spacelab.

In May, William J. Hamon, formerly my Director of Program Budget and Control in the NASA Headquarters Sortie Lab Task Force, moved to the Netherlands as the senior NASA Representative at ESTEC. Bill, accompanied by his wife, Bev, and their five children (the youngest only a year old), undertook this assignment with a great deal of trepidation. After a couple of temporary residences, the family eventually found a delightful house in the middle of the tulip fields and soon became acclimated to their new environment. Bill set up the NASA office at ESTEC, established liaison with the American embassy in The Hague, and paved the way for the many NASA employees who later transferred to or visited Europe. For the next 5 years, he provided direct communications between NASA and ESRO (later ESA) teams as we learned to work together and to implement the cooperative Spacelab program. His importance in creating good working relationships, mutual respect, and timely decision making cannot be overemphasized. In addition, his home provided a haven for NASA personnel in Europe and a place where social gatherings with our new European friends built friendships that strengthened the program and enriched our lives. William Davidson, a former MSFC Skylab Program Representative at Martin Marietta in Denver, soon joined Hamon to provide additional liaison between ESTEC and the technical team at MSFC.

Similar assignments were made from the European side. ESTEC assigned Robert Mory as its technical representative at MSFC. Dr. Christian Reinhold, formerly representing the European Space Conference in Washington, was reassigned to the new Spacelab Programme Office in ESRO Headquarters. His place in Washington was soon taken over by Wilfred J. Mellors, who occupied the post from September 1973 until his retirement in November 1983. Reinhold's assignment had been limited to the post-Apollo discussions; Mellor's assignment was broader and encompassed the full range of ESRO (later ESA) activities.

In addition to assignments of liaison people, organizational changes were made by both sides. The NASA Headquarters Sortie Lab Task Force was renamed the Spacelab Program Office in October 1973, with responsibilities for overall program planning, direction, and evaluation as well as establishing program and technical liaison with ESRO. The name change from Sortie Lab to Spacelab recognized the right of ESRO, as the sponsoring agency, to choose its preferred title for the program. MSFC was reiterated as NASA's lead center for the Spacelab program, and the task force there was also converted to program office status. Figure 26 shows how NASA and ESRO Spacelab program management was organized at this time.

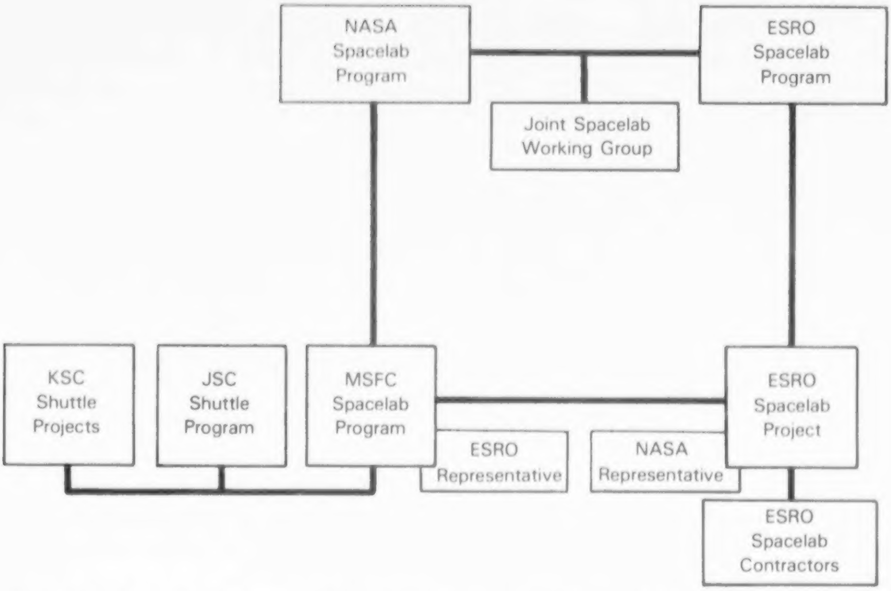

NASA Spacelab Program
ESRO Spacelab Program
Joint Spacelab Working Group
KSC Shuttle Projects
JSC Shuttle Program
MSFC Spacelab Program
ESRO Spacelab Project
ESRO Representative
NASA Representative
ESRO Spacelab Contractors

Figure 26. Spacelab management relationships as described in the Joint Programme Plan, September 1974.

Within ESRO, a Programme Directorate was established at the head office in Paris, reporting directly to the Director General, the chief executive officer of the agency. This was a deviation from previous policy wherein ESRO programs, once approved, were implemented by ESTEC, ESRO's field center in the Netherlands. In Spacelab, the organization was to be more parallel to the NASA setup, except that, as NASA Program Director, I reported to the Administrator through the Associate Administrator for Manned Space Flight, who also provided NASA Headquarters oversight to the Apollo-Soyuz, Skylab, Space Shuttle, and advanced manned programs, as well as mission and payload integration. There was no comparable intermediary in the ESRO organization.

SELECTION OF A PRIME CONTRACTOR

Time was approaching for ESRO to select the industrial team which would develop the Spacelab system. First, however, the Phase B studies would be completed by both agencies. On October 9 and 10, 1973, a review was conducted of the preliminary design effort conducted by MSFC. Members of the ESRO technical staff and contingents from each of the European prime contractors participated with NASA in the review. The first day consisted of a detailed examination of study elements carried out at MSFC as well as the Advanced Technology Laboratory (a dedicated Spacelab payload concept) work done at Langley Research Center and the contracted study work on the Sortie Lab by General Dynamics. The second day was devoted to splinter sessions at which each of the subject areas was reviewed in greater detail. MSFC had provided excellent full-scale mockups for both 12-foot and 14-foot-diameter Spacelabs.

Essentially the same group reconvened at Rockwell International (now the Shuttle prime contractor) in Downey, California for 2 additional days. The first day was devoted to presentations on the details and status of the Orbiter and overall Shuttle system, and the second day was devoted to splinter sessions according to subsystem, and details of interfaces between the Spacelab and Space Shuttle.

This review was immediately followed by a Phase B3 System Review of the ESRO contractors' efforts at ESTEC from October 30 to November 2. Presentations by the two contractor teams (led by MBB and ERNO) were followed by parallel subgroup discussions. The evaluation by the ESRO/NASA team resulted in a recommendation that each contractor be allowed to concentrate on its preferred concept for the balance of the Phase B3 effort. Very flexible concepts had been selected for payload accommodation that utilized both modularity and cargo aircraft features.

During the week of January 14-19, 1974, ESRO conducted another major review of its contractor study effort with NASA providing a strong support team. Termed the Phase B3 Subsystem Review, it was conducted at the home sites of the two prime contractors, ERNO in Bremen and MBB in Munich. The first morning at each site was spent in a system and program overview, and the following sessions were devoted to progressively more detailed subjects including individual subsystems, operations, payload accommodations, product assurance, test and integration, and program cost and management. The reviews also included inspection of full-scale soft mockups, and press conferences were held at each location (fig. 27). NASA astronaut Dr. Joseph Allen was the hit of the press conferences with his astronaut credentials and his German fluency. Both contractors' technical presentations were very impressive and both were most hospitable to the visiting ESRO and NASA representatives. It was obvious to them that the moment of truth was approaching.

The reviews were coming so fast, it is difficult to understand how the contractors had enough time to prepare their presentations. On February 12, the final review of Phase B3 was conducted at ESTEC with senior ESRO, NASA, and European national representatives in attendance. The presentations demonstrated a strong readiness by both contractor teams for the upcoming Phase C/D proposal effort. On the following day a Shuttle status review was presented by Dale Myers, and a Skylab program summary was given by Dr. William Lucas, the MSFC Director. These presentations were well attended and enthusiastically received by the European audience.

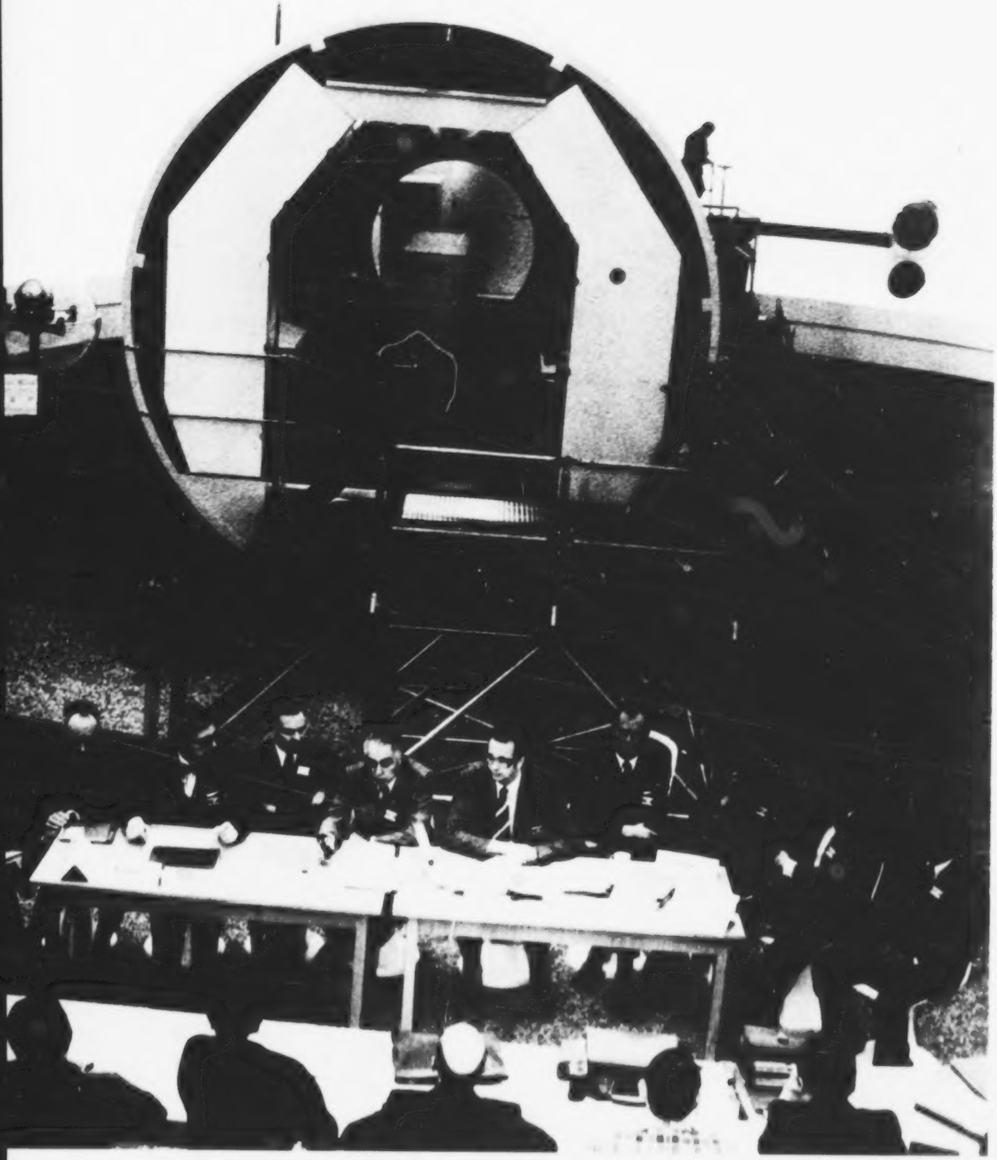


Figure 27. Press conference held at the ERNO site in Bremen, West Germany, January 15, 1974. Seated before ERNO's full-scale mockup of the Spacelab are, left to right, George Kennedi and Heinz Stower of ESRO, Douglas Lord and J.P. Causse (respectively, NASA and ESRO Spacelab Program Directors), Bernd Kosegarten, Hans Hoffmann, and Klaus Berge of ERNO, and Thomas J. Lee and Joseph Allen of NASA.

Just prior to these reviews, a NASA/ESRO Science Review had been held at ESTEC with the NASA team led by Dr. John Naugle, NASA Associate Administrator for Space Science, and Arnold Frutkin, and the ESRO team was led by Dr. Alexander Hocker, Prof. Maurice Levy, and Prof. H. C. Van de Hulst. This meeting was significant because it was the first serious discussion of the initial Spacelab mission. The group recognized that highest priority would of necessity be placed on Spacelab performance verification. Interestingly, agreement was reached that payload preference should be given to a few disciplines rather than trying to include experiments from many areas. This agreement would be changed later in the program.

At last, preparation was now under way on the long-awaited request for a proposal for the design and development contract (Phase C/D) by the ESRO project team at ESTEC. NASA's participation in preparing the request and in the entire evaluation process was a sensitive issue, but gradually an approach was worked out that would be satisfactory to both ESRO and NASA. NASA would review but not approve the work statement and the evaluation criteria, and it would review and approve the systems specification. NASA would play no role in the contract conditions, as they were considered to be solely ESRO's responsibility. During January and February 1974, a series of drafts of the documents was prepared and reviewed. NASA provided a few technical representatives at ESTEC to assist in the document reviews and conducted detailed reviews in parallel at NASA Headquarters and at MSFC. Finally, on March 1, the Request for Quotation (RFQ) was issued by ESRO to the two prime contractors, MBB and ERNO.

The principal technical document included with the RFQ was the Statement of Work with its two supporting documents, one on product assurance and safety implementations guidelines and the other on configuration management implementation guidelines. The Statement of Work contained the full scope of the contractor's tasks: management, product assurance, system engineering, documentation, manufacture, assembly, integration, testing, software, and operations support. It also contained a general list of all deliverable items including hardware, software, special services, documentation, and data.

A final document included the contract conditions, proposal conditions, geographical distribution, conversion table, and evaluation criteria. Two of these topics are worthy of special note, both being new to the NASA team. In the geographical distribution section, the prime contractors were directed to list the industrial members of their teams by nation and the amount of the contracted effort which would be subcontracted to each. The desire was to balance the distribution of expenditures on the program in the same approximate ratios as the contributions from the participating countries. Of course, since some subcontracts would probably be given to U.S. contractors (e.g., life support subsystems), it was understood at the outset that this geographical distribution could not be satisfied completely. At the time of the RFQ (prior to the entry of Austria as a participant), the distribution of support was expected to be as follows: West Germany, 54.1 percent; Italy, 18.0; France, 10.0; Great Britian, 6.3; Belgium, 4.2; Spain, 2.8; the Netherlands, 2.1; Denmark, 1.5; and Switzerland, 1.0.

The other topic of unusual interest was the conversion table, in which the Accounting Unit (AU) was introduced as a normalized currency rate for ESRO budgeting. NASA soon learned that ESRO team members were masters at handling finances in a multinational setup where relative values of national currencies were changing on a daily basis. The AU became the standard nomenclature for reporting the financial health of the program, and, at any given time, conversion could be made to any specific national currency. At the time of the RFQ, 1 AU was the equivalent of 1.2608 U.S. dollars. It was also defined by 0.88867088 grams of fine gold.

After a frenzied month of activity by ERNO and MBB, proposals were submitted to ESTEC on April 15, and the evaluation process began. It had been agreed that NASA would not participate in the Tender Evaluation Board, but would provide technical experts, as requested, to the supporting committees and panels. It was emphasized that these NASA personnel would be subject to the evaluation procedures as administered by the chairman of the ESRO Tender Evaluation Board and would conduct themselves in a manner befitting committee or panel members on normal NASA source evaluations. These individuals would be considered as technical experts and their recommendations or comments were not to indicate official NASA positions. The desire was to assure that ESRO had full responsibility for the evaluation process. To that end, each NASA representative received a letter of designation from me, as the NASA Spacelab Program Director, and was briefed on his responsibilities as a participant in the ESRO evaluation.

The competition between the two consortia had been intense throughout the Phase B definition effort and was to prove no less intense during the evaluation. In addition, the political overtones within West Germany could not be ignored, as MBB represented the southern part of the country and one of the two leading political parties, whereas ERNO represented the north and the opposing party. Nevertheless, the Tender Evaluation Board attempted to ignore these political pressures and to conduct an objective evaluation. The harder the evaluation committee and panels worked, however, the closer the two proposals seemed to get in total score. In the end, the final markings were almost identical. MBB, with its established capability as a prime contractor, was slightly ahead in the management area. The overall system proposals received virtually the same marks. ERNO's strengths were found in its system concept and with respect to satisfying potential users' needs. MBB was graded higher in its approach to product assurance and in its more conservative development schedule. In the subsystem area, ERNO ranked slightly higher because of its structural design and the degree of completeness of the design. MBB, on the other hand, received strong marks for commonality in ground and flight hardware and in its approach to manufacture, assembly, integration, and testing in the subsystem area. In total marking, the difference between the proposals amounted to only 12 points out of 1000 in favor of MBB. On the other hand, ERNO proposed a slightly lower price for both the development program and for subsequent production articles. Therefore, the Tender Evaluation Board judged both proposals to be broadly acceptable and was unable to recommend a choice between the two teams.

One important modification to the proposals made by the Tender Evaluation Board was to postpone the commitment for the Instrument Pointing System and to place with the selected consortium a definition study contract. The board made this recommendation because it believed that both bidders' detail in design and costing for the pointing system was inadequate for a hardware development commitment.

The Tender Evaluation Board report was made to ESRO's Adjudication Committee chaired by Director General Hocker on May 13. After listening to presentations from the major participants in the evaluation, the Adjudication Committee concluded there was a slight advantage in awarding the contract to ERNO based on the following factors: ERNO's technical concept was superior and employed low-cost design features, ERNO's depth of design was better for the immediate implementation of Phase C/D, the suitability of ERNO's concept to users' needs was superior, ERNO's proposal showed particular strength in the top management aspects, the shortcomings of the ERNO proposal could be repaired either more easily or later in the program, and ERNO's price was better.

Although this description is probably an overly simplified version of a very complex evaluation, the stage was set for final approval and award of the contract to ERNO. Before that could occur, however, there were to be a few sticky moments. The Memorandum of Understanding called for a yearly review of the Spacelab program by the ESRO Director General and the NASA Administrator. In view of the importance of the contractor selection, it was considered that this would be an opportune time for the first Director General/Administrator meeting, and it was scheduled for May 20 in Paris, so that ESRO could present the results of the evaluation.

Several of the NASA delegation had preceded the Administrator to Europe for a series of related meetings including detailed briefings on the proposal evaluation. When Dr. Fletcher arrived, the NASA delegation held a private strategy session to prepare him for the next day's meeting. All went smoothly until he discovered that both proposals reflected a significant loss in payload capability below what had been expected. Dr. Fletcher stated this was a no-go situation that would have to be resolved before he would agree to a go-ahead on the development effort. At the meeting with the Director General, this news was received like a bombshell! After considerable discussion it was decided to set up a quick and aggressive tiger team to perform a crash study before the next major deadline, the meeting of the ESRO Administrative and Finance Committee on June 5.

John Yardley, who had just replaced Dale Myers as the NASA Associate Administrator for Manned Space Flight, was immediately thrown into the fray. On June 3 he met with Dr. Hocker in Paris to review the results of the analysis by the joint tiger team and the contractors to restore much of the payload capability. Both ESRO and NASA representatives were impressed by Yardley's ability, using his pocket calculator, to dig to the depths of the problem and quickly bring some order to a chaotic situation. Key to Yardley's solution was to designate several categories of weights: Spacelab mission-independent subsystems, mission-dependent subsystems, the transfer tunnel, Orbiter support equipment, payload, and reserves.

With the modular system that was being planned for Spacelab, weights in the various categories could vary widely from mission to mission.

On the basis of a clear approach to charging Spacelab weights, some small adjustments in payload design goals and margins, the development of a weight reduction and control plan, and an agreement to define the weight and margin requirements in the Level 1 and 2 documentation, an agreement was reached. Yardley and Hocker thereupon signed an agreement stating that the payload goals would be as follows: Long module, 5500 kg; short module plus 6-9-meter pallet, 5500 kg; Pallet only—9 meters, 9100 kg; and Pallet only—15 meters, 8000 kg.

The agreement also stated that the following actions should be accomplished expeditiously: implement the proposed and accepted contract changes with respect to weight savings, analyze additional changes identified but not yet fully accepted, assign weight control engineers to the project team and initiate tight weight control activities, establish preliminary baseline weight goals and margins at the Preliminary Requirements Review, and reassess the entire weight status at the System Requirements Review.

Before signing the agreement, Yardley conducted a telephone conference with Fletcher, Dr. Rocco Petrone (now NASA Associate Administrator), and Naugle back at NASA Headquarters and received their concurrence. With this troublesome issue resolved, all agreed that it was appropriate to proceed with Phase C/D of the program. Yardley made it clear that NASA was not participating in the choice of the contractor, but he noted that NASA specialists supporting the ESRO evaluation had not identified any reason for advising ESRO to reconsider its choice of contractor.

Dr. Hocker concluded that from the weight exercise it was not necessary to amend the ESRO recommendation for the selection of the contractor. Therefore, on June 5 the ESRO Administrative and Finance Committee was invited to confirm the choice of ERNO as the team leader. Approval was granted at this meeting, and ESRO immediately announced the award to ERNO of a 6-year, $226-million contract for the development and construction of the Spacelab. The contract specified delivery of the first flight unit, fully qualified and ready for installation of experiments, by April 1979. Other major deliverable items included two engineering models (one for ESRO and one for NASA), three sets of ground support equipment, and spares. ESRO would be ultimately responsible for design, development, and construction of the Spacelab, which would be turned over to NASA for launch and operation. First launch was anticipated for early 1980. At last, development was under way!

Personal Reflections

A small but bothersome problem in the course of this program was the difference between European and U.S. practice in stating calendar dates. Whereas we are used to stating a date in the sequence of month/day/year, the tradition in Europe is to use the sequence of day/month/year (which obviously makes much more sense). So long as the month is spelled out, there is little cause for confusion; however, when expressed in numerical form, it was sometimes necessary to know the source of the reference material in order to know the intended date. Similar problems existed when the Europeans used periods where we were accustomed to commas to designate thousands or millions. Since old habits are the hardest to unlearn, we never found a way to avoid this confusion during the lifetime of the program. Fortunately, it caused no serious consequences.

The departure of J. P. Causse raised another issue characteristic of the ESRO (and now ESA) hierarchy. A very careful balance must be maintained among the nationalities of the top-level directors in the European space organization, so that each country feels that it is getting its fair share of the management plums. Thus when a vacancy occurs, it is usually filled with a person from the same country as the departing director. During the course of the Spacelab development program the director was always a French national, although the strong German support and interest in Spacelab would seem to have influenced the selection of a German Spacelab director.

In the area of Spacelab payloads, no program better reflects the changing moods of the science community and NASA management than the Atmosphere, Magnetosphere, and Plasma in Space (AMPS) program. This conglomeration of scientific experiments was generated in the early 1970s by the atmospheric science team at Houston and by the magnetospheric science team at Huntsville. It was studied for several years as a dedicated Spacelab mission payload under the auspices of a team at Marshall Space Flight Center. Then a decision was made to transfer responsibility to Goddard Space Flight Center. Manned payloads have always had to struggle for support at Goddard and this program was no different than its predecessors. Eventually, responsibility for AMPS was transferred back to Marshall, where, after some attempts to develop a viable mission, the program gradually died. Although there were many strong proponents for this dedicated mission, it could not withstand the budgetary onslaughts of the other science programs, and pieces of the payload were either delayed or assigned to other missions.

Looking back at the Donlan committee report, one can but wonder why so many changes occurred in the fundamental concept of Spacelab operations. Why, for example, did it become so difficult to send racks and pallets to users' facilities for the initial integration steps? And why, if most integration is now done at a single site, does it cost so much to integrate a Spacelab payload? What happened to the early sales features of Spacelab—quick and easy access by investigators, quick turnaround, and lost cost? We will return to these issues in later chapters. Perhaps all the decisions regarding centralization were not as good as they first appeared to be.

The early exchange of liaison personnel had many interesting byproducts. Pat Murphy, the new NASA European Representative in Paris, and his wife, Ruth, settled down in a top-floor apartment on the Left Bank that became a gathering place for visiting Americans. From their balcony one could look over the rooftops of Paris towards the Invalides, and from at least one vantage point, one could see the Eiffel Tower. More satisfying to me was the fact that they always had a supply of Fresca soda in their refrigerator. Pat could murder the French tongue, but, unlike the rest of us, he was not afraid to use the capability he did have, and he bailed us out of several tight situations in dealing with the local gentry. In at least one case, however, he failed to convince a taxi driver that he should give a ride to our visiting NASA Administrator.

I am sure our European counterparts could tell similar stories, but from our perspective, the impressions were quite different. When Robert Mory arrived at Marshall, he was quite distressed to be issued a contractor's badge, insisting in his best Gallic manner that he was not a contractor! Since NASA issued only U.S. government or contractor badges (or visitor passes), there did not seem to be any alternative but to issue him a contractor badge. Despite this temporary handicap, Mory soon became integrated into the Spacelab team at Marshall, was given full visibility into the NASA program activities, and provided valuable contributions to the flow of information and recognition of problems as they occurred.

In Washington the presence of Wilf Mellors also contributed immeasurably to the success of the program. Wilf, with his impeccable British accent, ready wit, and courtly manners, was an instant hit at NASA Headquarters. He was invaluable in providing both insight into the European decision-making process and immediate access to ESRO (ESA) administration.

As the Phase B definition studies were completed in Europe, visiting teams from NASA began to understand better the scope of the program and the capabilities of the European governmental and industrial team. We also began to experience many of the wonders of the continent, as we fanned out from Paris to visit, at least briefly, Amsterdam, London, Rome, and other famous cities that had been, heretofore, scenes in the travelogs of others. Our NASA liaison office at ESTEC soon was being driven crazy by our impossible requests for accommodations and travel arrangements. On one early visit to Amsterdam, some 40 of us found ourselves in a flea-bag hotel with shared bathrooms and a requirement to pay a deposit before being issued our room keys and towels. No visit to Amsterdam was complete without a walk along the canals and streets of the more tawdry neighborhoods and at least one gorging of ris-tafel, the Indonesion version of a bacchanalian feast. And this was not the only place where the rich foods and hearty wines were sometimes too much for us. I recall one layover in London when Sunday morning found a group of us in Picadilly Circus searching for a drug store to buy some Kaopectate medication for an ailing companion. And on another trip, O. C. Jean, our Marshall payloads expert, bemoaned the lack of good grits in Paris.

Of all these early trips to Europe, perhaps the most memorable for its social side was the one in January 1974 when the large team of NASA and ESRO representatives visited the facilities of ERNO in Bremen and MBB in Munich, the two competing companies for the lucrative Spacelab contract. In Bremen we were entertained by the Minister of Labor and Commerce at a reception in the historic and beautiful town hall and then given an exotic dinner complete with North Sea crab, venison, and an ice cream "bomb" in the picturesque Boettcherstrasse area. We were also introduced to the popular bratwurst stand near the Bremen market square and the Brau Haus, a beer hall laid out like a small town square. On the second night we were given tickets to a 6-day bicycle race in the Bremen Sports Center. This was a wild affair with a continuous beer party in the center of the track and periodic special feature races enlivening the competition. ERNO had arranged for visiting astronaut Joe Allen to present the prize for one of the sprint races it had sponsored. Beneath the stands was a series of booths providing a carnival atmosphere with, among other things, a complete ox roasting on a spit.

When we arrived in Munich, it was as if the MBB team had been told about the good time we had been shown in Bremen and was dedicated to outdo its ERNO competition. This time we were hosted at a reception in the Residence Hall of the Bavarian government, another large and ornate structure. After the obligatory toasts, the door opened and in walked waiters carrying silver trays of food. At first we selected the best spots to intercept the incoming trays, but soon we found that was unnecessary. What followed can best be described as a 33-course standup dinner! It had to have been experienced to be believed. The second night, as if to exceed the first, we were taken to a country inn where 220 of us took over the entire place for another extravaganza. A smorgasbord of food was washed down with 330 liters of beer, 195 bottles of wine, 22 bottles of schnapps, and I know I must have had at least 2 liters of orange juice by myself. I was in good company in this respect, as I was joined in my choice of libation by Ludwig Boelkow, the head of MBB. A three-piece band of zither, accordian, and contra-guitar kept us singing, dancing, clapping, and cheering between courses and late into the evening. I recall Max Faget, the veteran JSC design engineer, leading the group from atop a table in at least one chorus of "The Yellow Rose of Texas." A wonderful blond yodeler was the final "pièce de résistance." It may be hard to believe we did any work during this trip, but we actually had 6 full days of presentations, mockup reviews, press conferences, and facility visits during that same week.

The competition between ERNO and MBB was very interesting, which could be viewed quite dispassionately by those of us from NASA since we did not have to make the contract decision nor did we have to respond to the political pressures of the time. Nevertheless, we could not separate ourselves completely from the situation. ERNO was relatively unknown to us, and the ERNO team had never been a prime contractor with total system responsibility on a space development program. MBB, on the other hand, was better known, had demonstrated capability in managing satellite development programs, and had a superior facility. Subtle (and not so subtle) pressures were applied on some members of the NASA team to get them to influence the selection, but to my knowledge no NASA representative attempted to play such a role. When asked to evaluate portions of the proposal, we could be, and were, completely objective. Of course what transpired within the European evaluation process is known only to those participants. I have often wondered what would have been different in the course of the program if MBB had been selected as the prime contractor. In some ways, I feel the program might have progressed more smoothly, with fewer start-up problems and better project management of the industry team. On the other hand, MBB would have been a more independent contractor with which to work and a very difficult adversary in negotiating changes. On balance, I believe that the decision to select ERNO was a good one. Certainly it resulted in a great strengthening of the West German space industry.

One facet of the program which led to difficult decisions was the geographical distribution of the contractual effort. In attempting to spread contracts among all the contributing nations, and in further distributing effort within West Germany, some unfortunate marriages (at least in the eyes of NASA management) were forced. Thus the thermal control system was given to Aeritalia in Italy when it would have fitted more logically with the environmental control and life support responsibility assigned to Dornier System of West Germany. The assignment of software to Denmark was almost a make-work decision, since it should, more logically, have been assigned with the data system. In a similar fashion, the majority of the Instrument Pointing System development effort was given later to MBB to make up for its losing the prime Spacelab contract, even though primary responsibility for IPS was assigned to Dornier.

The final glitch in the contractor selection process caused by the weight problem was an unhappy situation that probably led to some unfortunate decisions, particularly with respect to the redesign of the pallets to the point where they are much too sensitive to handling. Part of the weight problem was caused by the flexibility of the design and the considerable change in chargeable weights for a given mission depending on what support equipment was required. The other problem is that the Orbiter landing weight fixed the total weight that could be accepted, and inadequate thought had been given to reserves for growth during the development process. Finally, the weight of chargeables to the Orbiter such as power kits, attach fittings, tunnel, and the heat rejection kit was unknown at the time. Once the agreement was signed on weight, it should be noted that the European team did a much better job of living within its weight margins than did NASA.

4 Solidifying The Requirements 1973-1976

SHUTTLE INTERFACES

Leaders in the Spacelab program recognized from the outset that significant changes in the Shuttle design could seriouly affect the Spacelab design. One early example occurred during discussions of a docking module. NASA Administrator James C. Fletcher, in a review of the Shuttle rescue situation in late 1973, defined a new baseline for Shuttle operations, as follows: Shuttle flights with more than three crewmen would carry a docking module; all other Shuttle flights would carry a docking module if weight and space were available; for rescue with a U.S. Shuttle vehicle, capability would be provided to carry to orbit and install a docking module on those Shuttle flights which did not carry a docking module; and for rescue with a USSR vehicle, the transfer mode would be IVA (internal) if a docking module was carried and EVA (external) if a docking module was not carried (fig. 28).

The reaction to this decision was immediate and widespread. In particular, ESRO officials expressed concern that the new baseline was established without giving ESRO an opportunity to express its view. They felt that the impact on Spacelab would be serious and would significantly reduce its usefulness and its capability for extended missions. ESRO was especially concerned that a succession of other weight restrictions had already been imposed on Spacelab. ESRO had first assumed the 65 000 pounds that could be carried to orbit by the Shuttle would be available for Spacelab. The return weight from orbit had subsequently been reduced, first to 40 000 pounds, then to 32 000 pounds.

Fortunately, Fletcher had also directed NASA to evaluate the impact on the mission model and on specific payloads. The matter was discussed at the Shuttle Level 1 Change Control Board meeting on November 16, 1973, and studies were initiated by both NASA and ESRO to evaluate the impact as well as alternative approaches to the docking module concept. By January 1974, the NASA Ad-

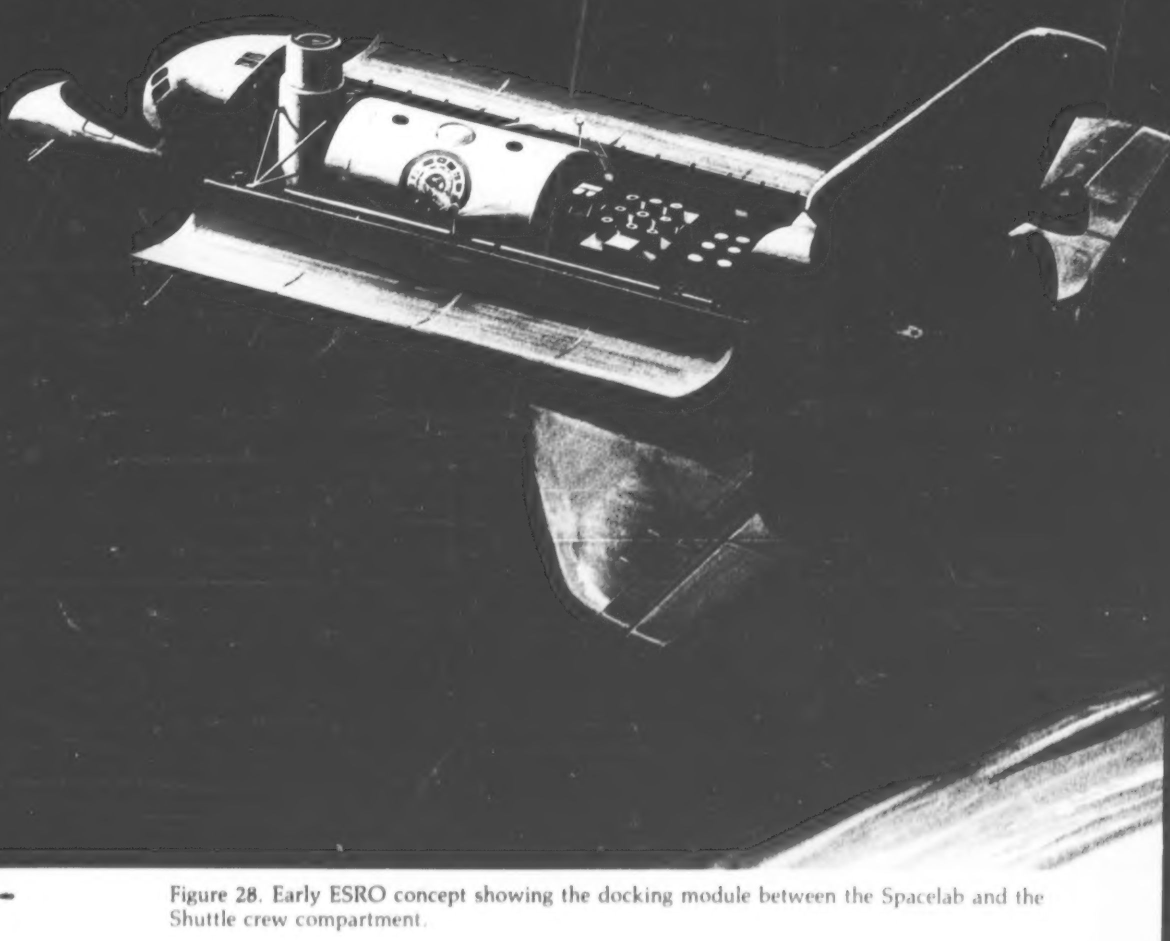


Figure 28. Early ESRO concept showing the docking module between the Spacelab and the Shuttle crew compartment.

ministrator had reversed his position and agreed with recommendations not to use a docking module on all Spacelab missions. The Spacelab design, however, was not to preclude the use of a docking module. The new baseline primary rescue mode would be EVA, with the Orbiter crew outfitted in conventional EVA space suits assisting the other crew members between the stranded and rescue vehicles in a universal, less maneuverable, but equally safe space suit (a spherical, pressurized cocoon). This decision resulted in a return of some 2000 pounds of payload capability to the Spacelab. It was also agreed that an EVA hatch would be baselined in the tunnel connecting the Spacelab module with the Orbiter mid-deck. The idea of using the Spacelab scientific airlock for planned or emergency egress was rejected.

The issue of the tunnel had been resolved earlier to ESRO's advantage; the Memorandum of Understanding had specified that it would be developed by NASA. Prior to the 1973 Woods Hole Summer Study, it had been recognized that in order to satisfy Orbiter center-of-gravity constraints, Spacelab would have to be placed in the rearward portion of the cargo bay. Therefore, when a Spacelab module was flown, a lightweight tunnel would have to be provided to gain access from the Orbiter crew compartment (fig. 29). In effect, the forward portion of the cargo bay could not be utilized except by structures of relatively low density.

The question of Spacelab heat rejection had been the subject of many studies, from initial concepts that envisioned the Spacelab pivoted out of the cargo bay to provide adequate area and look angles for its own surface-mounted radiators, to the accommodation of deployable radiators from the Spacelab while the module itself remained fixed within the cargo bay. By early 1974, the Orbiter design had progressed to the point where it carried a full complement of radiators and could guarantee sufficient capability to meet Spacelab's needs using Orbiter radiators mounted just inside the cargo bay doors. The Orbiter would reject up to 8.5 kw, from the Spacelab with coolant conditions from approximately 5° to 40° C.

A similar decision was reached early in the program with respect to providing electrical power for Spacelab subsystems and payloads. The Orbiter's peak requirements for electrical power would occur during launch and descent. While on orbit, the Orbiter would require less power, and with its excess capability, it could dedicate the output from one fuel cell to the Spacelab. In view of Europe's lack of development experience in fuel cells and the cost to develop its own system, ESRO readily agreed to this approach. The Orbiter would provide 7 kw, and 12 kw, peak for the Spacelab while on orbit.

Another issue subject to considerable discussion was the relationship of the diameter of the Shuttle Orbiter cargo bay and the size of the Spacelab. From the Orbiter standpoint, development funding was very tight and a reduction in size could reduce development costs and provide a little budgetary cushion for the program. On the other hand, many users, in particular the Department of Defense, supported the 15-by-60-foot cargo bay. Studies were conducted of reducing the Spacelab diameter from 14 feet to 12 feet, and full-scale mockups of Sortie Module concepts were used to demonstrate that the smaller dimension was acceptable. A smaller module and pallet would make both ground and air transportation easier, and since

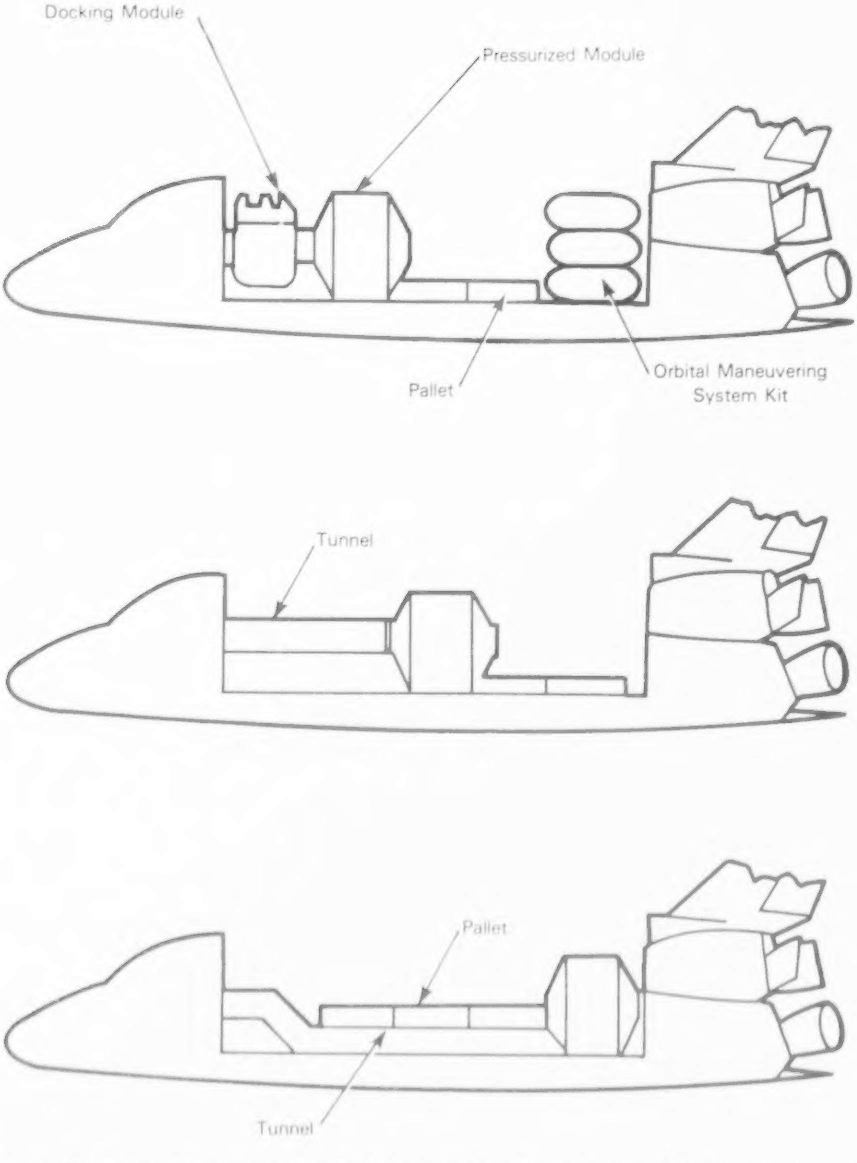

Docking Module
Pressurized Module
Pallet
Orbital Maneuvering System Kit
Tunnel
Pallet
Tunnel

Figure 29. Three early concepts for docking module and transfer tunnel locations to provide an acceptable center of gravity for the Spacelab payload.

the early operational concept involved frequent shipment of these Spacelab elements during integration, this was not an insignificant factor. After many arguments, the decision was made to build the Orbiter to the larger dimension. It was then decided that to take full advantage of the available volume, the outside diameter of the Spacelab module would be 14 feet (4.3 meters). The racks to be mounted within the module, and the pallets, however, would be designed for ground transportation. In the case of the pallets, this posed a fairly difficult design compromise for the contractor, Hawker-Siddeley Dynamics (later British Aerospace), which, in order to reduce the height of the pallet for clearance of highway overpasses, was forced to change the cross-section of the pallets and incorporate a removable keel fitting.

WORKING RELATIONSHIPS

Design problems such as these were not the only problems facing the program. Now that the competition between ERNO and MBB was over, a new working relationship was evolving among the principal participants, one which became readily apparent at the first Phase C/D meeting at the ERNO facility in Bremen, June 24-28, 1974. NASA and ESRO representatives had spent the previous week at ESTEC reviewing all aspects of the proposal baseline and deciding about an accumulation of recommended changes. When the team arrived in Bremen, however, it was quickly evident that a new era in the program had begun. ERNO took a strong position that all actions and changes proposed by ESRO were out of scope. This would be the beginning of a long series of confrontations between the two parties on changes, with NASA always standing in the wings as an interested observer and, at times, as instigator of the trouble. Within ERNO, it was clear that the "2-meter twins" (so called because of their height), Hans Hoffmann, Technical Director and Spacelab Program Manager, and Bernd Kosegarten, Business Director, had taken control of the company from the old guard and were going to use the Spacelab program to make a name (and a profit) for their company.

ERNO had assembled an impressive team of co-contractors to accomplish the development phase of the program. Aeritalia (Italy) would be responsible for the module structure and overall thermal control, ENGINS MATRA (France) the command and data management, AEG-Telefunken (W. Germany) the electrical power distribution including the harnesses, Dornier System (W. Germany) the environmental control, Hawker-Siddeley Dynamics (U.K.) the pallet structure, Bell Telephone Manufacturing (Belgium) the electrical ground support equipment, INTA (Spain) the mechanical ground support equipment, Fokker (the Netherlands) the scientific airlocks, SABCA (Belgium) the utility bridges (structural supports for bridging the electrical harnesses and plumbing lines between pallets or between the module and pallet) and igloo structure, and KAMPSAX (Denmark) the computer software. INTA's assignment later was taken over by SENER. In addition to its European resources, ERNO was relying heavily on U.S. consultants from McDonnell Douglas and TRW during this early phase of the program.

It is appropriate to review the origin and contributions of these consultancies. With the demise of NASA-funded Space Station studies, the McDonnell Douglas team at Huntington Beach, California was casting about for some kind of follow-on activity and was approached by ERNO in late 1972 to present the results of its company-funded studies of the Sortie Module. While North American Rockwell and Grumman had similar discussions with ERNO, McDonnell Douglas was asked to provide four consultants for one-on-one support to the ERNO Spacelab Project Manager, the Chief Engineer, the Environmental Control Life Support Engineer, and the Programmatic Cost Analyst. Donald Charhut had made the presentations to ERNO in December 1972 and led the McDonnell Douglas team that was in place by February 1973. Charhut vividly recalls the team's arrival at the Bremen airport in a snowstorm with the 4 men and their wives, 10 children, 6 dogs, and the mass of luggage required for a permanent move by the 4 families. The ERNO welcoming party was more than a little taken aback. Nevertheless, this was the start of a very fruitful participation by the McDonnell Douglas consultants. They eventually numbered as many as 35 at ERNO in Bremen, 5 at Aeritalia in Turin, and 2 at Fokker in Amsterdam and provided advice and leadership in the areas of systems engineering, thermal control, structures, avionics, and business activities. They provided key support during the Phase B studies and the proposal preparation period and then stayed on as consultants during the development period until the engineering model was delivered to NASA in 1980. In order to reduce overhead charges to the parent U.S. company, a German corporation, McDonnell Douglas Technical Assistance Service, GmbH, was established.

Prior to its involvement in Spacelab activities, TRW had had a longstanding agreement with several members of the European MESH consortium to help design satellites. TRW had also provided direct support during the early 1970s to Marshall Space Flight Center payload studies in the areas of space physics, materials processing, and Earth resources, so it was well-acquainted with the potential payloads being considered for the Spacelab. ERNO approached TRW to see if it could provide support in this important area, as well as in avionics. The initial team of five TRW people, led by William F. Rector, III, arrived at ERNO in May 1973 and contributed to the effort through the Phase B studies and proposal preparations. After ERNO won the contract, the TRW team was expanded to as many as 25 people through 1978, most of them at ERNO in Bremen, but some at MATRA near Paris and at BTM in Antwerp. Both MATRA and BTM played significant roles in the avionics area of the program. Much later in the program, TRW was instrumental in solving software problems. In general, the relationship between the TRW and McDonnell Douglas consultants was very smooth, with complementary responsibilities established between the two groups and accepted by ERNO. Both groups of consultants were effective in demonstrating to ERNO that managers must penetrate by in-depth questionning, particularly at co-contractor reviews, where the conventional German approach would normally be formal and standoffish.

In the summer of 1974, an aggressive effort was made to assure that all elements of the Spacelab team were equally informed on all aspects of the program. Some 60

Europeans, both ESRO and industry representatives of the Spacelab team, embarked on a 2-week visit to the United States. From July 15 to 19 they met with NASA representatives at Marshall Space Flight Center. The Europeans were led by Heinz Stoewer, who was the acting Program Director for ESRO, and Hans Hoffmann, the ERNO Project Manager. As Program Director, I led the NASA delegation with Thomas (Jack) Lee, MSFC Spacelab Manager; Jack C. Heberlig, Space Shuttle Payload Coordination Manager at JSC; and Jack Dickinson, KSC Spacelab Manager. Following a general briefing session, meetings of technical specialists representing each major subsystem, operations, design, and programmatics were convened. In these meetings, representatives of the Spacelab program and the contractors focused on clarification of requirements, design details, and interfaces. On July 22-23 the Spacelab team visited JSC for technical discussions of the primary Shuttle/Spacelab interfaces: power, environmental control and life support, structures, avionics, and mission operations. By this time, a soft mockup of the Orbiter aft flight deck was available at JSC for review. The aft flight deck was to become the primary location for control of the operational interfaces between the Shuttle and the Spacelab.

EVOLUTION OF THE CONCEPT

Changes in the top-level program requirements during the early years of the program from 1973 to 1976 provide a vivid picture of how the Spacelab concept evolved. The first document, the "Level I Guidelines and Constraints for Program Definition," was approved by the program directors (Causse and me) on March 23, 1973. It addressed seven general characteristics of the program: programmatics, systems, operations, interfaces, user requirements, safety, and resources. In the programmatics section, the document provided definitions of terms to be used in the program, called for delivery of the flight unit in late 1978 or early 1979 (with the engineering model to be delivered 1 year before), and specified the use of the International System of Units (metric system).

The systems section was the most extensive portion of the document. It specified a nominal mission capability of 7 days with extended duration capability up to 30 days and orbital inclinations from 26° to 100°. It called for a design life of 50 missions or 5 years and a mission success goal of 0.95. This mission goal reflected a willingness of the program management to accept the fact that 1 mission in 20 might be terminated without obtaining any experimental data from the Spacelab. It was hoped that this would reduce both development and operational complexity and costs by not trying to achieve the more typical goal of 0.999 for a manned mission. It was not intended to imply any reduction of safety for the crew members.

In terms of weight, the total for a Spacelab mission was not to exceed 80 percent of the Shuttle nominal performance, with an experiment payload of 12 000 pounds (5443 kg) for the module case and 20 000 pounds (9072 kg) for an all-pallet mission.

(Note that the Shuttle nominal performance called for a capability to place 65 000 pounds in low Earth orbit and to return 32 000 pounds to the landing site.) The crew size would be from four to eight with two to six of those available to concentrate their work on the Spacelab and its experiment payload. To a great degree, the Spacelab was to be autonomous, but from the start it was recognized that the Shuttle would provide transportation, crew accommodations, stabilization and control, guidance and navigation, and ground communication. The Spacelab was to have all the versatility that could be provided by a laboratory within the cost constraints.

Other requirements specified in the early document were deployment, (rotating the Spacelab 90° to provide improved cooling and better look angles), easy ground handling, shirtsleeve environment, on-the-ground maintenance and easy accessibility, a 1-g (single orientation) layout, and minimum contamination and electromagnetic interference. Ground support equipment was to be provided for ground checkout and the system was to be fully qualified prior to flight, insofar as practical. In other words, there would be no flight test period. Spacelab would carry a useful payload on its first mission.

From an operations standpoint, the Guidelines and Constraints Document called for communication and control through the Mission Control Center at JSC, network control as specified by the NASA Office of Tracking and Data Acquisition, data management and experiment integration under the control of MSFC, and ESRO to be responsible for the integration of experiments and data management on any experiments it sponsored. The interface section stated that interfaces with the Shuttle would be "standard," that user provisions would reflect a low-cost approach, and that the environment would be specified later. The user requirements section referenced the current outputs from the various payload working groups.

In the safety area, the early safety guidelines document was referenced and requirements were stated for a safety plan, for safe mission termination, for protection devices against hazards including experiments, and for extravehicular activity and rescue. Finally, in the resources section, it was made clear that cost would be a major factor in design and operational concept decisions, with production and operational costs to be minimized.

By the time the second issue of the Guidelines and Constraints Document was signed on September 21, 1973, several new decisions were reflected. First, it was recognized that the high-inclination missions would be launched from the West Coast, rather than from KSC. Second, the design life was extended to 10 years rather than 5, and the maximum crew size was reduced to 7. There was some reduction of the module payload to 5000 kg, but a 6000-kg payload was now specified for a module-pallet combination. It was now recognized that the Shuttle would provide electrical power and that the Spacelab would remain fixed within the cargo bay (i.e., no deployment). The new document also required that the external contamination level be maintained below Class 100 000. It stated that a Tracking and Data Relay Satellite System would be available when the Spacelab became operational. It now specified a reference environment which had been issued by the Shuttle program and referenced user requirements as defined by the NASA-ESRO Joint User Requirements Group. The document also reflected full responsibility for rescue on the Shuttle program.

The third issue on March 5, 1974 recognized the new status of the approved program. The document was renamed the "Level I Programme Requirements Document." The use of the term "programme" reflected one attempt at an early accommodation to our new European partners. Robert Lohman and Dai Shapland were the primary authors of the early Level I documents, and the term "programme" was the only concession ever made of this nature. ESRO staff members from the United Kingdom, as well as other European participants schooled in Oxfordian English, often disliked some Americanizations of words and phrases. Their preference for the terms centre, manoeuvre, and "aluminium" is a typical example. "Shedule" versus "schedule" was a common pronunciation difference that cropped up in briefings. In the later stages of the program these differences were much less important, but in the early days they were sometimes major points of contention.

The March 1974 document also reflected some new or altered requirements. The slippage of the delivery of the flight unit into 1979 was clearly recognized. The paragraph on autonomy had been deleted and the surviving facets of this topic were covered in the Shuttle interface paragraph. The laboratory versatility requirements had become more specific, with a listing of common payload support equipment to be provided, that included a large scientific airlock, one high-quality window and one viewport for science and applications observations, one or more work benches, and a film vault. Although the limiting dimensions of 15 feet by 60 feet had not been changed, the minimum module size was to accommodate 5 cubic meters of experiment equipment volume, and a 15-meter-length of combined pallet segments was to be provided. The new document also recognized that the transfer tunnel must have variable lengths to accommodate the most extreme positions of the module as required to meet Orbiter center-of-gravity constraints.

In the operations section, the new Programme Requirements Document specified a horizontal attitude for most ground operations but also required a capability for the Spacelab's rapid removal from the Orbiter while in a vertical position on the launch pad. During mission operations, the desirability of interaction between ground-based experimenters and the Spacelab crew on orbit was now recognized. In the Shuttle interface section, a work station on the aft flight deck was identified as a requirement, and the specific 7 kw_e power supply and 8.5 kw_t heat rejection quantities were identified. By this time, the safety section had been expanded to cover both product assurance and safety, with particular references to reliability and quality assurance approaches. A new paragraph on software standards and guidelines had also been added to the systems section.

After issuance of the March 1974 version, a NASA-wide review of the document was initiated to assure its readiness to serve as the top-level control document for the upcoming Preliminary Requirements Review, scheduled for early November. The new version of the Programme Requirements Document (Revision 1) was signed on September 26, 1974. The Level II System Requirements Document, which contained more detailed requirements and was controlled by the program technical managers at MSFC (Lee) and ESTEC (Stoewer), underwent similar review and revision.

Probably the most important change in the revised Programme Requirements Document was the weight section, which reflected the agreements reached between Yardley and Hocker (chapter 3). Specific payload weights were identified for the long module, for the short module plus 6- to 9-meter pallet, and for the 15-meter and 9-meter pallet-only configurations. In each case a development reserve had been established equal to 20 percent of the estimated hardware weight and also a payload growth reserve had been set aside for, in most cases, 20 percent of the required payload weight. In two cases, there was an additional nonallocated reserve. Gradually, through the life of the program, these weight reserves were utilized to meet emerging needs.

A new requirement for high-data-rate, digital, analog, and video recording was now specified, as was a vacuum vent for the users. The four levels of integration which had been identified in the Donlan committee study (chapter 3) were now used to describe ground operations. In the flight operations section, control of the Spacelab module and igloo resources by the basic Orbiter crew was specified for the first time. Finally, two new topics were added to the product assurance and safety section, though in title only for the time being: caution and warning subsystem and materials control.

Almost a year to the day later, on September 24, 1975, Revision 2 of the Programme Requirements Document was issued. By this time, the Spacelab development hardware weight reserves had been released to the project managers and were no longer under Level I control; however, the 20 percent payload growth reserve was still being held by the program directors. One new requirement appeared in this version, which was to provide limited access for equipment servicing during ground operations in a vertical position. As a goal, access to experiments in the module was to be possible up to 4 hours before launch and immediately after landing. The driving force behind this new requirement was the life science users, particularly because of their use of living specimens. More is said later about this difficult challenge and how it was addressed.

Two new requirements indicated how the interface between the Obiter and the Spacelab was becoming more complex. The Orbiter was to provide the oxygen supply for the Spacelab air revitalization system, as well as a master timing signal. The promised words about caution and warning had been filled in, requiring an independent, hard-wired, and automated system for emergency parameters. The sections on materials control had also been completed, indicating there would be no relaxation of manned space flight standards for the basic Spacelab or its subsystems, although relaxed requirements would be permitted for experimental payloads.

The major change to this revision was the addition of four updated sections taken from the Preliminary Joint Program Plan, which had been issued July 30, 1973, prior to the signing of the Memorandum of Understanding, and subsequently revised September 26, 1974. The four sections transferred from the Joint Program Plan and now incorporated into the Level I Programme Requirements Document

(PRD) covered agency responsibilities, program milestones, deliverables, and documentation. With this issue the PRD was placed under a change control procedure so that proposed changes could be submitted by anyone within the program. These changes would be considered at joint meetings between ESA and NASA.

On July 30, 1976, further changes were approved. The most important ones noted the addition of NASA-furnished utility connectors (from Orbiter to Spacelab) and a trace gas analyzer. The latter was a significant factor in the drive to reduce materials testing on experiments to be carried within the Spacelab module because it would give immediate warning to the crew in the event of toxic offgassing. (Unfortunately, after several years of development, the trace gas analyzer fell victim to schedule delays and rising development costs and was canceled). Other changes noted at this time were specific Interface Control Documents to provide the physical, functional, and procedural interfaces between the Spacelab and the Space Shuttle, Level II guidelines for the first and second Spacelab flights, the Joint Configuration Management Plan to provide necessary procedures for effective control over all products (documentation, hardware, and software) of the program, and a requirement for two additional program reviews: the Ground Operations Requirements Review and the Flight Operations Requirements Review.

FIRST MAJOR REVIEW

Now that the requirements documentation was becoming firm, it was time for the first of the major development program reviews, the Preliminary Requirements Review (PRR) (figs. 30 and 31). Although the original ESRO schedule in the Joint Program Plan had envisioned only one requirements review (a Design Requirements Review), NASA soon convinced ESRO that a two-step approach was preferable. The first review (PRR) would assess the contractors' specifications and plans at the system level and a second Subsystem Requirements Review (SRR) would update the system requirements and establish the co-contractors' subsystems level requirements baseline and plans for implementing the requirements.

There would be three baseline documents for this first review: the Program Requirements Document (Level I), the System Requirements Document (Level II), and the Shuttle Payload Accommodations, Volume XIV. A fourth document, the Spacelab Payload Accommodation Handbook, would be available and changes to it could be proposed; however, it would not become a controlling document until the Preliminary Design Review.

The normal approach to a review such as the PRR is to establish a series of technical panels whose members review the contractor documentation and write Review Item Discrepancies (RIDs), noting faults in the documents and making recommended changes. Each team would then review the RIDs submitted by its team members and recommend a proper disposition, for example, rewrite, approve, disapprove, or study further. A preboard would then be convened at the next higher

Size	● Within orbiter payload bay dynamic envelope (~ 15 × 60 feet)
Weight	● Level III specification weights, based on present weight estimates, and design target weights (10% below spec. weights) will be specified for each flight configuration
Center of Gravity	● Within orbiter center of gravity envelopes
Crew Size	● Maximum three persons per shift (four persons for 1 hour)
Induced Loads	● Spacelab to withstand orbiter and environmentally induced loads under all operating conditions ● Spacelab not to cause catastrophic orbiter failure under crash landing conditions
EVA	● Not required for subsystem operations
Orbiter Interface	● Compatibility with physical and functional interfaces for • Attachments • Primary power supply • Coolant loop • Data transmission and reception • Oxygen supply and air revitalization system

Figure 30. Major design requirements for Spacelab at the time of the Preliminary Requirements Review.

Flexibility	● Two module sizes and various pallet lengths to meet variety of user demands
Simplicity	● Minimum experiment and orbiter interface changes for different module and/or pallet flight configurations
Reusability	● 50 reuses, 10-year life
Mission Support Capability	● Nominally for 7-day mission, extendable to 30 days
Reliability	● 0.95 for 7-day mission
Safety	● Fail-safe philosophy for essential subsystem functions ● Safe-life for pressure shell and tanks

Figure 31. Functional requirements for Spacelab at the time of the Preliminary Requirements Review.

management level to review the proposed RIDs from all the teams and accept or modify each team's recommended dispositions. Finally, a board made up of senior management officials would review the work of the preboard and make final disposition of the recommended changes. This procedure would be done first by the government agency and then in conjunction with the prime contractor.

In the Spacelab program, a new approach was needed because of the intergovernmental nature of the effort. After receipt of the data package from ERNO on October 21, 1974, independent technical teams were set up by ESRO at ESTEC and by NASA at MSFC. The teams conducted their reviews and wrote RIDs during October 21-31. Each agency then convened a preboard to screen the recommended changes and decide which ones should be submitted for joint evaluation. The NASA preboard met at MSFC on October 31 and November 1. The next step was taken at ESTEC from November 4 through 6, where joint ESRO/NASA technical teams combined, clarified, categorized, and screened the proposed changes to the various contractor specifications and plans and identified where changes to requirements were necessary. After the specialist teams had completed their work on the more routine proposals, a joint preboard co-chaired by Wolfgang Nellessen for ESRO and Luther Powell for NASA tackled the difficult job of making specific recommendations on all the other proposals. On Saturday, November 9, the senior ESRO/NASA board co-chaired by Heinz Stoewer and Jack Lee reviewed the most difficult decisions and decided how best to discuss them with ERNO.

The final week of the PRR was conducted at ERNO during November 11-15 and was primarily an ESRO/ERNO show, with NASA attendees as interested bystanders. Again the routine of technical teams, preboard, and board was followed. Our ESRO colleagues did a wonderful job in objectively presenting the NASA-generated changes as well as their own and kept the NASA team fully informed of the actions taken. By the time the review was completed, 1233 RIDs had been considered, of which 1077 were approved, 56 were withdrawn, and 100 were to be studied more before final disposition. The large number of open studies was of special concern to program managers because so many problems would need to be resolved before the SRR. To expedite some of the more critical studies, special meetings and working groups were established with broad membership. These groups paid particular attention to avionics and mechanical interfaces with the Shuttle.

OTHER REVISIONS

From the beginning of the program, both the ESA and NASA teams recognized that the Spacelab data management system would be their most difficult technical challenge. One of the first issues was which computer system to select for the centralized processing function. The Shuttle program had already selected the IBM model AP 101 to handle the myriad onboard calculations required by the Orbiter. The basic design concept for the Spacelab envisioned three onboard computers, one to handle the subsystems, a second to satisfy experimenters' needs, and a third to serve as backup. The principal purposes of the onboard computers would be to provide status verification, fault detection, and fault isolation of selected functions of subsystems and payloads and to provide a sufficiently flexible processing capability to accommodate expected user requirements.

From the outset, it appeared that the IBM computer selected for the Shuttle would also be satisfactory for the Spacelab and would have the additional advantages of commonality (for long-term operations) and ready availability of replacement components and service within the U.S. However, the European perspective was quite different. To the ESRO team, the selection of the computer was an emotional as well as a pragmatic issue. Since the Spacelab was to be European developed, ESRO believed that the computer should be a European product. In addition, the ESRO administrative and finance committee, in giving the go-ahead to hire ERNO as the prime contractor, had directed ESRO to reevaluate the computer selection to see whether a common computer system could be used for Spacelab ground support equipment as well as for the flight unit. A technical team of ESRO, ERNO, and NASA computer experts reviewed the available candidates, including the IBM computer and several European systems. It was clear, however, that ESRO had been encouraged to come up with a European solution. After the joint team had concluded its findings, a new entrant was introduced into the competition, an extension of a military/commercial combination developed by the French Compagnie Internationale pour l'Informatique (CII) called Mitra 25. Since this new system was competitive to the IBM AP 101 in size, weight, and performance and since the compatibility with the ground version provided an additional benefit, NASA accepted ESRO's choice of the Mitra 25 system in December 1974.

A similar but less political issue developed with respect to the air revitalization system. The Orbiter system had not been sized to provide environmental control and life support for a manned module such as the Spacelab in addition to supplying its own needs. Therefore, the Spacelab was to have its own system to provide atmosphere, humidity control, and CO_2 absorption for the payload crew while they were working in the pressurized module and the transfer tunnel, as well as to provide air and fluid cooling loops for the subsystems and experiments within the module and a fluid cooling loop to the pallets. There was a concern that the Spacelab and Orbiter control systems would counteract each other in controlling pressure or temperature when both systems were active, due to the tolerances in the respective control systems. As these problems were analyzed, it became evident to both sides that the Orbiter cryogenic tanks, sized to provide oxygen and hydrogen for the fuel cells, actually had a surplus of makeup oxygen. It would thus be possible to use this excess oxygen to supply Spacelab needs and delete the Spacelab oxygen bottles. Although early indications were that this decision to connect the two oxygen systems had to be made by mid-December 1974, it was not reflected in the Spacelab Programme Requirements Document until September 1975.

Another troublesome decision related to the transfer tunnel which would connect the Orbiter mid-deck to the Spacelab module and provide for ready transfer of the crew from one habitable volume to the other. The size, shape, and location of the tunnel was also related to decisions about the Orbiter airlock required for crew EVA operations. One proposal would have provided a flexible installation so that the airlock could be placed within the mid-deck compartment of the Orbiter, and by reversing its mounting fixture in the forward bulkhead of the cargo bay, the airlock could be placed within the cargo bay, providing more space for crew activities within the mid-deck. A third position for the airlock could be to mount it above the transfer tunnel and so provide the capability for simultaneous operations between the Orbiter and Spacelab during EVA.

After much discussion, two important decisions were made. First, in January 1975 it was agreed that the transfer tunnel would be offset below the Orbiter centerline so that lightweight payloads could be mounted on bridging structures above the tunnel if desired. The tunnel would have a joggle at the aft end, however, so that entrance to the Spacelab module would be at its centerline (fig. 32). This would enable the forward and aft end cones of the module to have common structural design.

The second decision, in March 1975, established the approach to the Orbiter end of the tunnel. The Shuttle program would build a removable tunnel adapter which would be placed between the Spacelab tunnel and the Orbiter cabin wall. The adapter would have doors at both ends and a third door at the top where the versatile airlock could be mounted. It was anticipated at this time that on Spacelab flights employing the pressurized module, the airlock would be mounted above the tunnel adapter providing simultaneous EVA and Spacelab operations. However, this concept gradually eroded as the cost of such operational changes became known. The decision was made to leave the airlock fixed within the Orbiter cabin and to evacuate the crew from the Spacelab module and close off the door between the tunnel adapter and the tunnel should EVA be required on a Spacelab module mission. (The Orbiter cabin was considered to be the "safe haven.") Although to the purist this was a poor decision, since EVA could no longer be possible while the crew was conducting operations from within the module, in actuality it has not proved to be a difficult constraint since few, if any, Spacelab users have requested EVA in support of their experiments. In most cases, EVA is required only as a last-ditch effort to correct a failure of a Spacelab component, for example, closing the scientific airlock hatch or locking or jettisoning the Instrument Pointing System. These actions are necessary to permit closure of the cargo bay doors and safe return of the Orbiter and its payload.

SECOND MAJOR REVIEW

Following the completion of the Preliminary Requirements Review, steps were taken toward the second major program review, the Subsystem Requirements Review (fig. 33). It had been anticipated that the SRR would take place in the spring

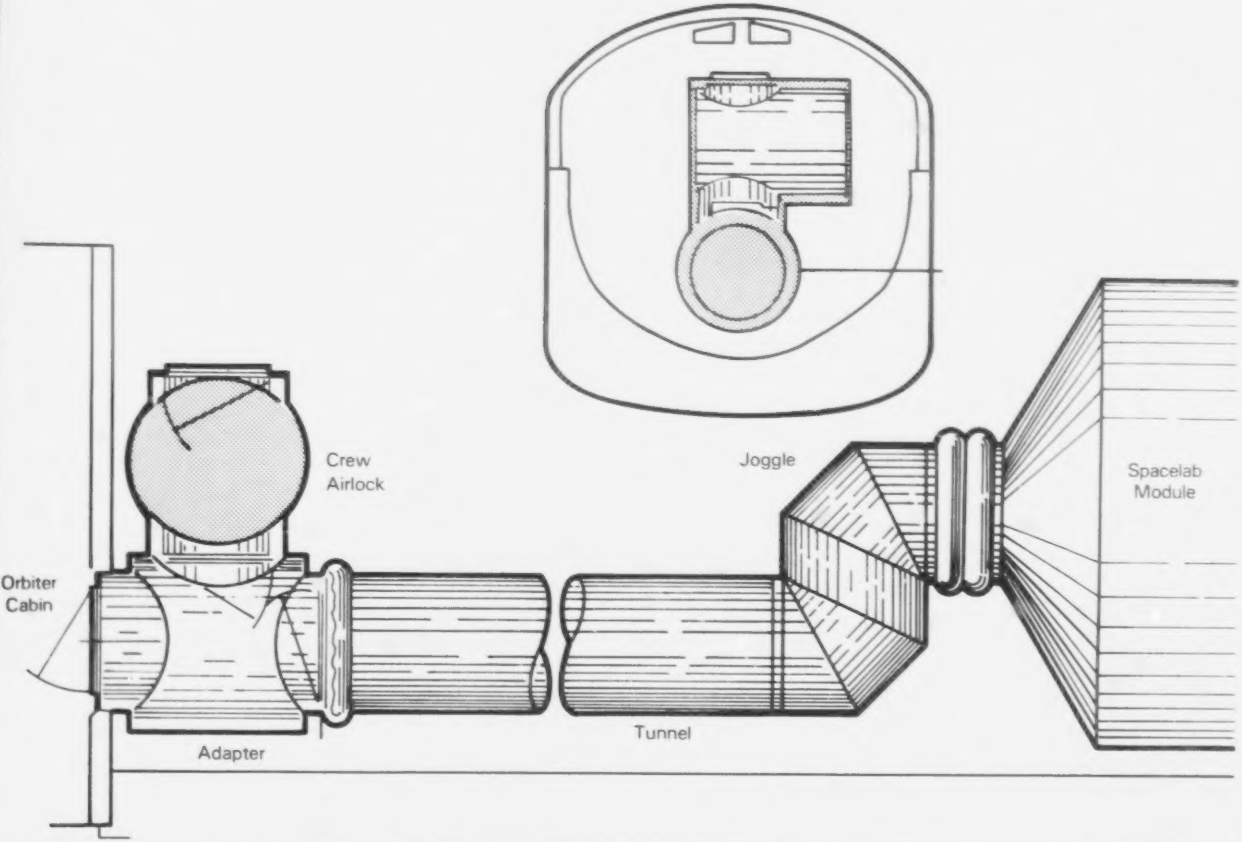

Crew
Airlock
Joggle
Spacelab
Module
Orbiter
Cabin
Adapter
Tunnel

Figure 32. Offset concept for the transfer tunnel showing the joggle required to permit centerline entrance to the Spacelab module.

of 1975. However, the many studies that had to be performed, the preparation by the contractor of 38 review documents, and the processing of required changes to the System Requirements Document soon made it apparent that a schedule delay would be necessary. It was finally decided that the review documents would be delivered in two packages, the first to be received by NASA on May 8 and the second on May 17. NASA's 10 teams and ESA's 12 teams (ESA had teams in management and project control which were not matched by NASA) immediately began their technical reviews and writing RIDS. The NASA Preboard "N" chaired by Jack Lee conducted its review at MSFC on May 29–30, 1975. In the meantime, ESA had been conducting a parallel review. (Note that the long-awaited single European Space Agency was now a reality.)

On June 6, the recommendations of the NASA preboard were presented to John Yardley and others from the Headquarters program offices to obtain their advice and concurrence. Of the 1300 proposed changes submitted by the NASA team members, some 900 were to be submitted to ESA. On June 9, the combined ESA/NASA teams met in Noordwijk to consider all the RIDs (1772) prepared by both agencies.

After review by the joint technical teams, an ESA/NASA preboard co-chaired by Otto Steinbronn for ESA and Luther Powell for NASA again reviewed the recommendations and selected 10 of the most difficult RIDs to present to the joint board co-chaired by Stoewer (ESA) and Lee (NASA). The final "bean count," as it was familiarly termed, showed 1279 RIDs to be submitted to ERNO. At this point, an important step was taken to improve the upcoming review at ERNO. As RIDs were approved, they were given to ERNO in advance of the arrival of the teams at ERNO so that impact evaluations could be performed by the contractor. Thus when the ESA/ERNO teams convened at Bremen during the week of June 16, ERNO was in a better position to indicate what the impact would be to implement the proposed RIDs. Again, as at the PRR, ESA carried the ball in presenting all the proposed changes to the contractor, with NASA in an observer role.

One further change was made in this review. After the final ESA/ERNO board meeting, ESA and NASA convened a joint post-SRR board to review those changes which had been resolved differently from what had been agreed to earlier by the joint ESA/NASA board. All in all, the SRR was a great success with considerable improvement in the professionalism of the entire review and with good information exchange. This is not to say that no problems were identified. Particular concerns were systems engineering inadequacies, access to the results of engineering changes, cost and schedule impacts of changes, and plans for subsystem Preliminary Design Reviews and for the total system Preliminary Design Review, the next major milestones in the program.

One further subject should be mentioned before leaving the Subsystem Requirements Review. A high point was a chance to visit ERNO's full-scale soft mockup of the Spacelab module, shown in figure 34. For the first time, one could see in three dimensions what the SRR was all about. The mockup gave a good idea of such critical factors as accessibility, maintainability, habitability, interfaces,

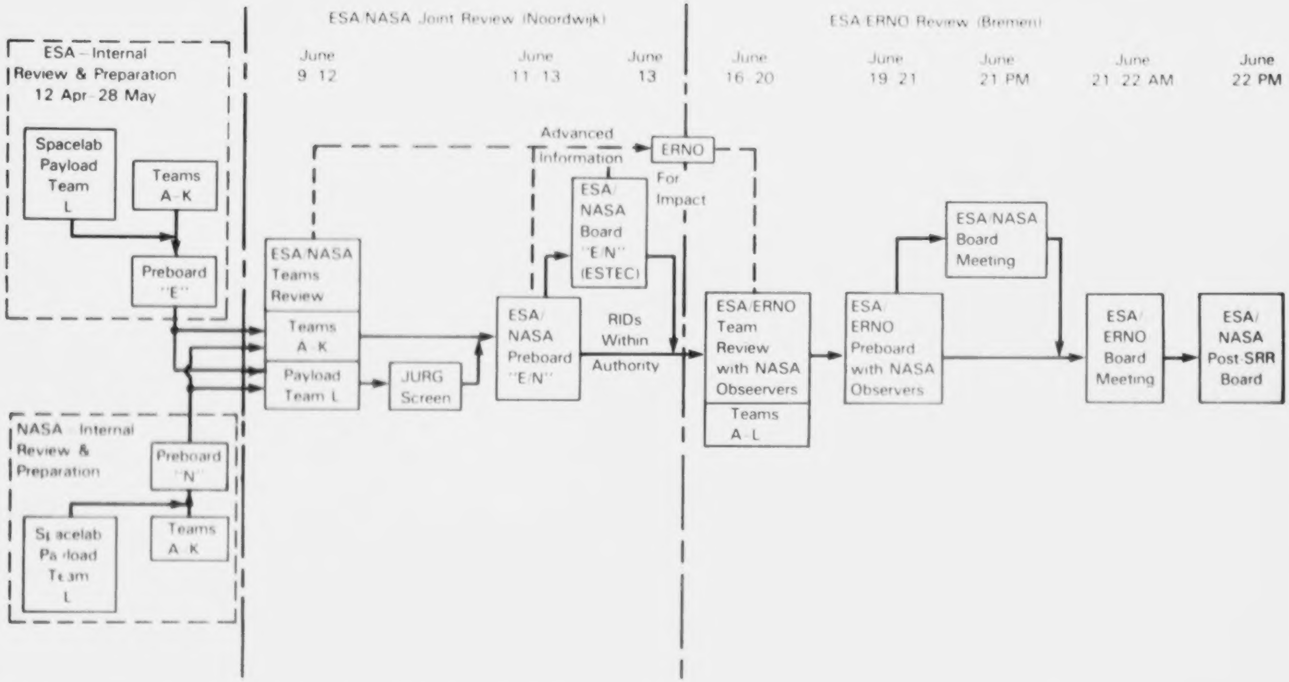

ESA/NASA Joint Review (Noordwijk)
ESA/ERNO Review (Bremen)
ESA – Internal Review & Preparation 12 Apr–28 May
June 9–12
June 11–13
June 13
June 16–20
June 19–21
June 21 PM
June 21–22 AM
June 22 PM
Spacelab Payload Team L
Teams A–K
Preboard "E"
Advanced Information
ERNO
For Impact
ESA/NASA Teams Review
Teams A–K
Payload Team L
JURG Screen
ESA/NASA Board "E/N" (ESTEC)
ESA/NASA Preboard "E/N"
RIDs Within Authority
ESA/ERNO Team Review with NASA Obseervers
Teams A–L
ESA/ERNO Preboard with NASA Observers
ESA/NASA Board Meeting
ESA/ERNO Board Meeting
ESA/NASA Post-SRR Board
NASA – Internal Review & Preparation
Preboard "N"
Spacelab Payload Team L
Teams A–K

Figure 33. Planned approach for the Subsystem Requirements Review.

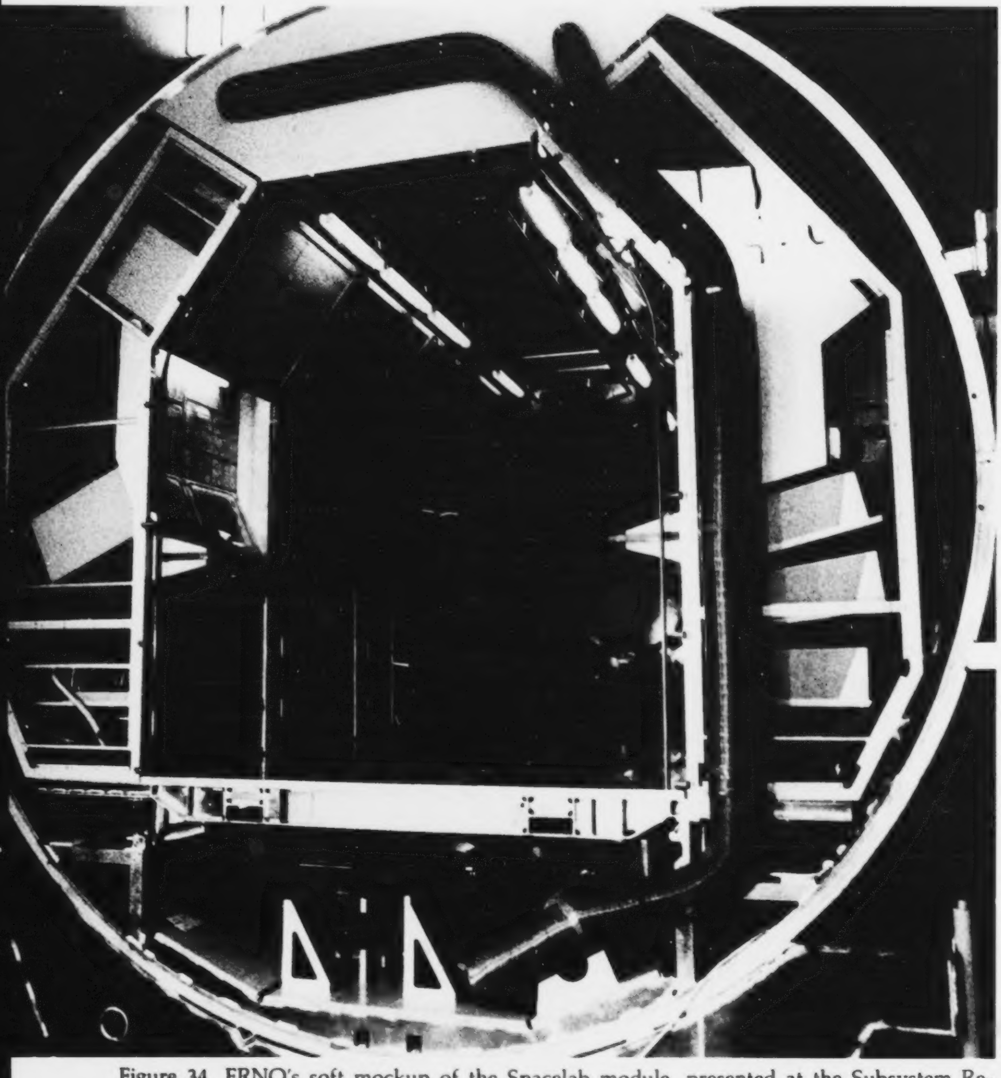


Figure 34. ERNO's soft mockup of the Spacelab module, presented at the Subsystem Requirements Review, June 16-20, 1975.

lighting, colors, interior configurations, and component arrangements. The early concepts of subsystem locations, floor and rack assembly procedures, wiring runs, cooling ducts, foot restraints, control center, work bench, and storage containers could also be seen. The mockup of the module was considerably more advanced than that of the pallet, which was only approximated in plywood form. Nevertheless, the entire assemblage was very helpful to the reviewers by indicating where the paperwork was leading.

WORKING OUT THE BUGS

In addition to the major reviews, another means for defining the program, improving relationships among the participants, and facilitating the flow of information was the creation of additional joint working groups. In January 1974 it was proposed that a Spacelab Operations Working Group be established to discuss flight, ground, crew, and launch operations. The March 19, 1974 meeting of the Joint Spacelab Working Group established this new working group with the thought that it would have a limited life, possibly through the Critical Design Review. In actuality, the Operations Working Group continued not only beyond that time, but eventually was divided into two groups, one focused on ground operations, the other on flight operations. These groups contributed substantially to problem resolution in their respective areas through the time of the Spacelab 2 mission.

A second group established about the same period was the Software Coordination Group. Its initial focus was on the HAL-S and GOAL languages which were to be furnished to ESRO by NASA, but it quickly broadened its scope to include microprogramming, European computer languages, interactive display languages, and user requirements for onboard computing.

A third working group was established by agreement of the program directors on November 7, 1974: the Shuttle/Spacelab Interface Working Group on Avionics, or, as it was soon to be called, the Avionics Ad Hoc Group. It was evident that the July meeting at JSC to discuss the Spacelab/Shuttle interface had opened up many more questions that it had answered. The new group, co-chaired by Franco Emiliani for ESA and Luther Powell for NASA, met from December 1974 to March 1975 and recommended solutions to a number of interface incompatibilities between the Orbiter and the Spacelab. The most difficult problem was telemetry synchronization, and the group's solution to this was fully accepted. Other recommendations were not fully accepted because of their significant cost impact, but were extensively reviewed by both ESRO and NASA. These recommendations covered such subjects as closed loop TV, audio communications, command and control, caution and warning, electrical power, and Spacelab resources control.

In March 1975, Bernard Deloffre became the ESRO Spacelab Program Director. He replaced Heinz Stoewer, who had been Acting Program Director as well as Project Manager since the departure of J. P. Causse. Deloffre had been the French Chief

Executive of the Symphonie Satellite program and former Director of the CNES Space Launch Centre in Kourou, Guiana. As soon as he had participated in two meetings of the Joint Spacelab Working Group, visited various European and U.S. program sites, and observed the Subsystem Requirements Review, he was anxious to reduce the number of open issues in the program and focus program efforts in a positive fashion. At a meeting in Washington, August 28-29, 1975, Deloffre and I drafted a "package deal" that would commit our respective agencies to develop or fund activities and equipment which had been in question. On September 24 in Paris we signed the package deal agreement after having reviewed the respective commitments with our own management. This was a major accomplishment that resolved many issues dating from the beginning of the program.

In the agreement, ESA accepted development and funding responsibility for a remote control capability from the aft flight deck, an improved version of the remote acquisition unit, a multiplexer, recorders, a peaking battery, a vertical access kit, an improved venting facility for experimenters, center aisle racks, resources during ascent and descent, and water and freon coolers. NASA agreed to take over funding and development responsibility for the tunnel ground support equipment (GSE), utility leads, workstands, an external hatch, air coolers, transporters, the trace gas analyzer, and strongbacks and slings for hoisting the assembled Spacelab. ESA also agreed to study plans for atmospheric scrubbing, to equip the igloo with subsystems, and to make programmatic improvements in the performance specifications and test program for the Instrument Pointing System. Both sides accepted the recommendations for a GSE working group on the delivery of unit testers. NASA agreed to procure from ESA a high fidelity mockup if adequate fidelity could be provided within the cost limit of 2.5 million accounting units. We relinquished our requirement for a Spacelab-to-Orbiter interface simulator and a mechanical simulator. Finally, it was agreed that we would not provide ESA with a fully equipped and integrated set of Shuttle interface verification equipment.

The package deal would be costly to both sides. Although no funding amounts were stated in the agreement, estimates as high as $35 million for ESA and $13 million for NASA were quoted. Nevertheless, the agreement represented a major accomplishment in a number of important areas that would enhance the Spacelab system and its operation. For the most part, NASA's acceptances represented a willingness to absorb some of the costs necessary to operate the system in the U.S. Although all the agreements were not carried through to completion, the more important ones were, to the benefit of the overall program. That the balance on this particular agreement seems to have been tipped in NASA's favor is not a realistic assessment, since NASA accepted responsibility for a number of items that normally would be provided by the developer. Fair appraisal would say that the package deal was a good agreement for both sides and, more importantly, was good for the program.

Looking back at the early goals for the Sortie Lab, it is interesting to consider how changes in requirements affected the end product, Spacelab. The first desired characteristics advertised for the Sortie Lab emphasized four distinct areas: low cost, laboratory versatility, minimum interference with Shuttle turnaround, and rapid experiment cycle—concept to reuse. Low cost was to be achieved through simplicity, with minimum new development and use of ground lab equipment on board. There is no question that the final Spacelab has become quite sophisticated, although there was only a small number of new development items. However, the use of ground lab equipment has been realized only to a very small degree.

To achieve laboratory versatility, the early dreams envisaged multi- or single-discipline missions, providing a large pressurized module with a shirtsleeve environment, an unpressurized instrument platform with wide viewing angles, and experiment installation possible at the user's facility. Except for the last objective, today's Spacelab does provide all these benefits and more.

To achieve minimum interference with Shuttle turnaround, it was proposed to keep the interface simple and to conduct the primary checkout independently. I do not believe any of us knew just how complicated the Shuttle/Spacelab interface would become. In fact, the Spacelab is a very definitive part of the Shuttle system and the most complicated interface the Shuttle has had to address. Nevertheless, the principle of separate checkout has been maintained, and the final checkout with the Shuttle is really of very short duration. Thus one would have to conclude that the interference with Shuttle turnaround has been minimal.

The dream of a rapid experiment cycle has not been realized. It was originally thought that with direct user involvement, minimum qualification requirements, and minimum documentation the cycle could be appreciably less than in previous manned programs. But delays in Shuttle development, increases in operational costs, and reduction in number of flights have made this dream unattainable. Perhaps as the Shuttle begins to operate on a more regular basis and the backlog of very complicated early Spacelab missions is reduced, this goal may become a reality.

The story of the igloo is also an interesting aspect of Spacelab history. It was felt that the Spacelab should provide a single interface with the Shuttle regardless of the configuration selected for a given mission. The module, with its sea-level shirtsleeve atmosphere, provided a natural protective environment for the Spacelab subsystems. The data management system would need a similar habitat for the pallet-only mission; thus a pressurized canister, the igloo, was designed to be placed on the forward bulkhead of the first pallet. In effect, then, the interface wiring and plumbing to the Shuttle would be identical in the two configurations (fig. 35).

The ESRO and ERNO plan was to outfit the igloo only to the degree it was absolutely necessary. Subsystem components that could be moved from module to igloo, or vice versa, would not be provided to NASA in duplicate. This was a disastrous situation. One could visualize trying to process, in parallel, a module and pallet-only configuration at the launch site and continually borrowing boxes from one test setup to check out the other. My most important achievement in signing with Deloffre the package deal was to get ESRO to include two sets of subsystems. Since a full set of Spacelab hardware included the long module and five pallets plus an igloo, this commitment to two sets of subsystems gave to NASA, in effect, at

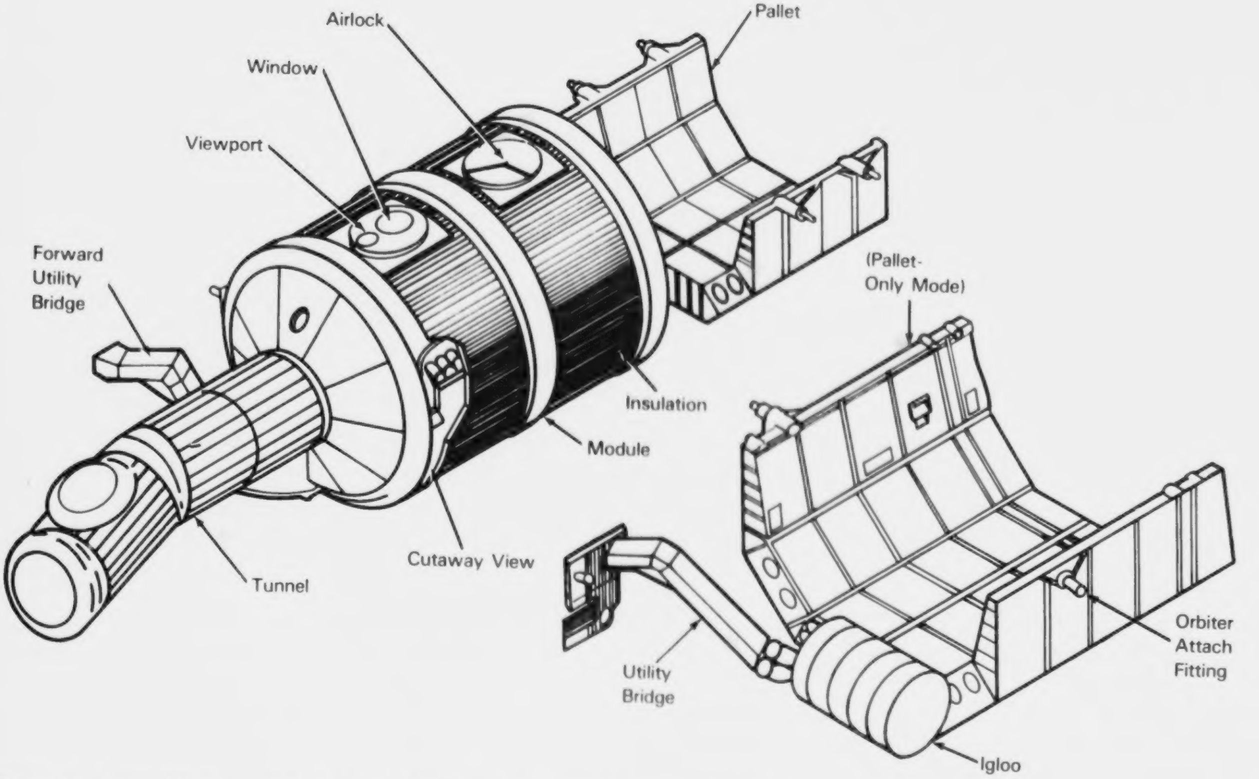

Airlock
Pallet
Window
Viewport
Forward Utility Bridge
(Pallet-Only Mode)
Insulation
Module
Cutaway View
Tunnel
Utility Bridge
Orbiter Attach Fitting
Igloo

Figure 35. External features of the Spacelab showing Orbiter-attach fittings and igloo to provide a standard interface for pallet-only and module missions.

least two Spacelabs. When it came time for NASA to commit to the purchase of a second set of flight hardware, an exact duplicate of the first unit gave NASA a very effective inventory of Spacelab elements for its planned needs, although additional components were added to the follow-on production order to provide operational spares and flexibility of hardware use.

The interface problems between the Spacelab and Shuttle required more than just good negotiating—they demanded much innovative engineering and hard work by teams of specialists on both sides of the interface. The Shuttle program started out with the very strong position that any payload to be flown within the cargo bay would have to meet the interface as established in the Shuttle Payload Accommodations Document, Volume XIV. Spacelab would be treated no differently than any other payload. Of course, those of us in the program felt that Spacelab was different than the other Shuttle payloads because it stayed attached to the Shuttle throughout its mission and provided, in effect, an extension of the Shuttle's capability as an orbital laboratory. It was thus a part of the Shuttle and should be addressed with more consideration.

Eventually, Shuttle program managers succumbed to our entreaties and agreed to develop detailed Interface Control Documents that defined in detail every electrical pin connection, data transfer, fluid coupling, structural attachment, and software relationship necessary to effect the marriage of the two systems. In at least one respect, the Shuttle program went beyond the call of duty in developing the Shuttle mixed cargo harness, a flexible set of utility connectors within the cargo bay, so that Spacelab and other payloads did not have to fabricate individual harnesses to the forward bulkhead of the Shuttle cargo bay. Larry Williams at JSC deserves primary credit for this innovative concept.

Another interface calling for innovation was the relationship between Spacelab and the ground processing facility at KSC. ERNO's concept for Spacelab assembly required a horizontally oriented facility. In its Integration Hall at Bremen, ERNO planned to use commercially available and modular workstands that could be assembled around the mechanical ground support equipment to provide access for the assembly and checkout team. When the KSC team members first saw this concept, it was obvious to them that these portable stands would not be satisfactory at KSC for repeatedly processing Spacelab elements over the operational lifetime of the program. One night in a Washington-area motel, a group of MSFC and KSC engineers discussed some ideas and came up with the basic concept of how the KSC Spacelab integration process could be handled. This group was led by Ralph Hoodless from MSFC and Jack Dickinson from KSC and leaned heavily on the creative genius of Ernie Reyes from KSC. They conceived of a series of horizontal rails and workstands on which the Spacelab elements and its payload would be assembled and checked out. After returning home, the KSC Spacelab team developed the concept in greater detail, using the former Apollo Operations and Checkout Building as its planned base for assembly and checkout operations (fig. 36). They first proposed to change the name of this building to the Spacelab Processing Facility, but this proposal was rejected and the name O&C Building was re-

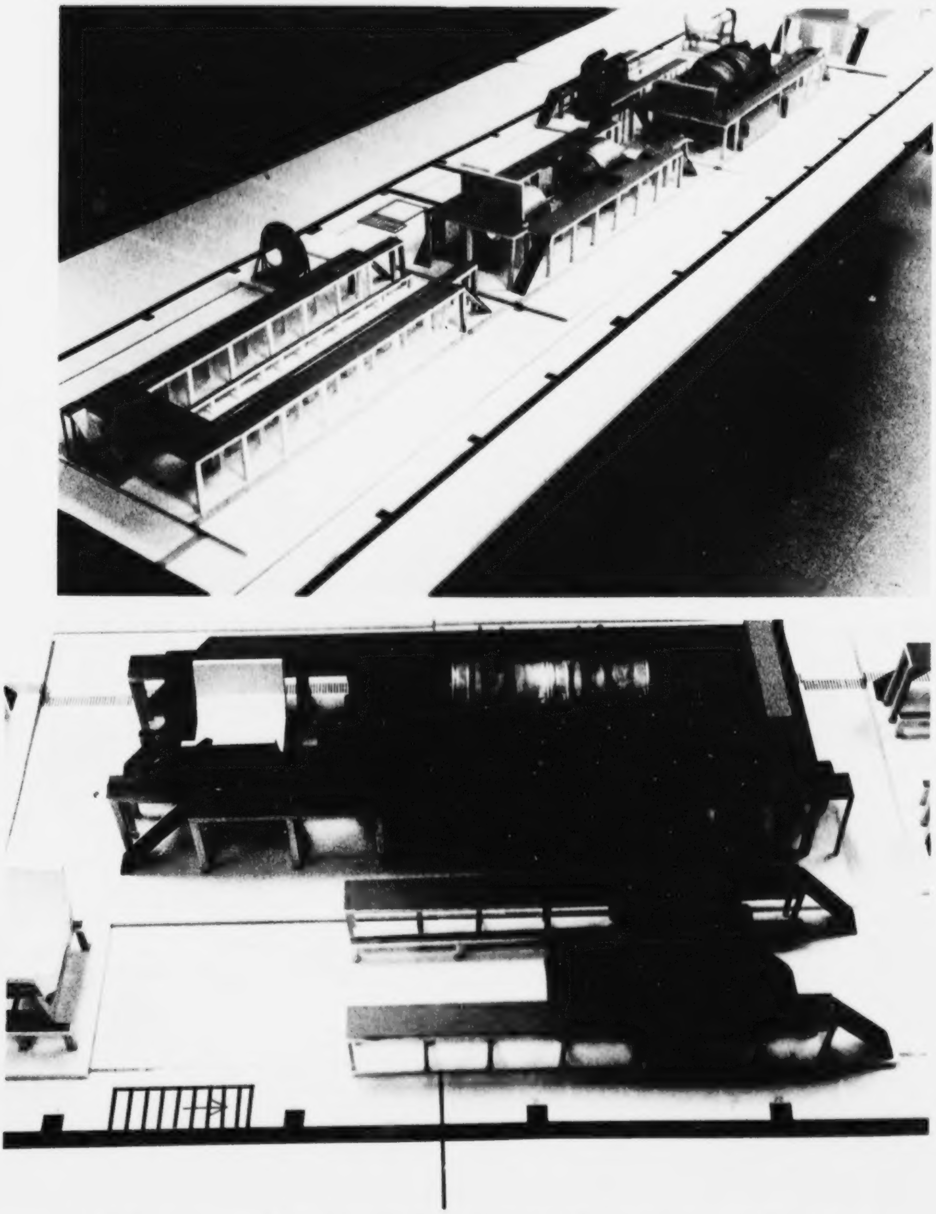


Figure 36. Two views of the Kennedy Space Center model for the proposed Spacelab processing facility.

tained. The main high-bay areas were almost completely stripped of stands previously used for Apollo processing before construction of the Spacelab workstands. In the adjoining rooms, similar modifications were made to provide supporting facilities for the Spacelab electrical ground support equipment and for Spacelab users. That today this is a very effective and busy facility attests to the wisdom of that first group of planners. Although one can still find supporters for the vertical assembly approach, the horizontal system has worked very well.

Personal Reflections

It has been my experience that each NASA Administrator leaves his mark on the programs under his leadership, and Spacelab is no exception to that rule. I have already mentioned Dr. Fletcher's strong reaction to the weight problem at the time of the development contract award and his desire to provide a hard-docking capability for all Spacelab missions. He provided strong guidance on other occasions during the formative stages of the program. One was in directing us to plan at least half of the Spacelab missions as pallet-only configurations, i.e., no module was to be carried. This stemmed from his reaction to the criticism of classical space scientists who felt that a manned laboratory within the cargo bay was an unnecessary appurtenance to the mission of conducting scientific observations from the Shuttle. Although we had planned from the outset to provide pallet-only mission capability, the ground rule of half and half seemed completely arbitrary. I felt that the configurations should be dictated by the specific instruments selected to be carried on scientific missions.

Another area in which Dr. Fletcher exerted influence was in ruling out a cooperative approach to planning the second Spacelab mission payload. Again, it was understood from the start that Europe's development role would not be completed until the two principal configurations, module plus pallet and pallet only, had been demonstrated successfully in the first two missions. The Memorandum of Understanding had specified that the payload on the first mission would be jointly shared. It was mute, however, on the subject of the payload for the second mission. It did state that further cooperative use of the Spacelab would be encouraged. Dr. Fletcher recognized the precedent that would be established if both missions had cooperative payloads and was further aware of possible objections should Europe seize too many of the benefits from the early Spacelab missions, particularly in its chosen field of emphasis, materials processing. He made it clear within NASA that the payload on the second mission would be a U.S. payload. Of course, individual experimenters in Europe would be free to respond to the Announcements of Opportunity, as always on NASA payloads, but the development of the total payload would not be a jointly planned effort, as on Spacelab 1.

In at least one instance, Fletcher showed his dismay over some of the trends in Spacelab program management. Jack Lee, our program manager at MSFC, was briefing the Administrator on the requirement for NASA personnel to support the program. MSFC, in particular, had established an extensive team to support the European development effort. In addition to Lee's program office, the MSFC Engineering Directorate provided a large team of technical specialists to review ESA's and ERNO's efforts and to develop NASA support hardware and lay the groundwork for future NASA operations of Spacelab. Finally, in utter frustration, Fletcher blurted out: "I can't understand why it is necessary for you to have 120 people in order for us to get a free Spacelab."

The role of the two principal industry consultants to ERNO, TRW and McDonnell Douglas, was also interesting to observe at the start of the program. The two U.S. contractors, experienced in working with NASA in both the manned and automated satellite programs, attempted valiantly to introduce to ERNO and its cocontractors the engineering techniques, operational experience, and management procedures that had proven so successful in NASA programs. They soon learned that they were working with a different group of people. The European engineers found it difficult to believe that NASA could insist on so many details, and reports, and reviews, and presentations. They were used to being given a job and left alone to produce the results. The ceaseless requirement for documents, reviews, and traceability throughout the program was hard for them to comprehend.

For our part, NASA managers were often appalled at some of ERNO's presentations, in which the most obvious shortcomings would be glossed over or ignored. We kept asking the McDonnell Douglas and TRW people why they could not get ERNO to do things the right (i.e., NASA) way. Similarly, we could not comprehend the lack of penetrating questions by ESA and ERNO top management at the regular program reviews. In defense of the U.S. contractors, it should be pointed out that they were working hand in glove with the Europeans on a continuing basis and actually had much better respect for their knowledge and problem-solving approaches than did those of us who only visited their sites periodically. Granted, the Europeans did things differently, but that did not necessarily mean they were wrong. The trick was to differentiate between tasks which had to be done a certain way and those which did not.

"Working off" open items is a good example of where changes in procedure were necessary. At major program reviews, action items were identified and assigned to the contractors, to ESA, or to NASA. The U.S. consultants at ERNO were surprised to find that actions assigned to ERNO were being closed out with no apparent explanation of the disposition of the particular action, be it a study, a specification change, or the like. The consultants discovered that when an action was assigned to an ERNO employee, it was immediately marked "closed." The procedure was soon changed to close an action only when the proposed activity had been accomplished and properly certified.

Establishing the requirements for Spacelab took many years and was fraught with many difficult decisions. Certainly the most troublesome factor was the changing design status of the Shuttle. In reality, NASA and ESRO were trying to design both the Spacelab and its carrier at the same time. While our European partner requested firm specifications on which to base its design of the Spacelab, the Shuttle was continuing to change. As the approach and landing tests and other Shuttle qualification programs provided new test data, additional changes were made. When the Europeans accepted our recommendations to use some common hardware items, they sometimes found themselves having to qualify hardware for use in Europe before it was needed in the Shuttle schedule. While this caused delays and cost increases for the Spacelab program, a joint NASA/ESA Working Group on Spacelab Orbiter Common Hardware helped to minimize the problems.

Although much of my emphasis in this chapter is on the evolution of the Programme Requirements Document, a similar process characterizes its more detailed technical backup, the System Requirements Document (SRD). At the risk of betraying the confidences of good friends, I must tell the story of the beginning of this Level II document. Frank Sperling, one of the first ESRO Spacelab team members at ESTEC, was assigned the task of preparing the first draft. On an early trip to Marshall he was approached by Hans Palaoro of the Marshall Sortie Lab Task Force, who asked if Sperling was to prepare such a document. Sperling replied that indeed he was, but he had no idea where to start (knowing Frank and the ESA team, I am sure this was more than a slight exaggeration). Palaoro then informed him that in the course of the Sortie Can study effort, he had already prepared a draft SRD. Unfortunately, he was unable to give ESRO a copy as he had been directed to destroy it and had just torn it up and put it in a wastebasket in Room 4261.

Sperling, having only a half-hour to spare, hurried to Room 4261 where he dumped the entire contents of the wastebasket into his suitcase and headed home. When he arrived in the Netherlands, a customs official looked askance at the dirty coffee cups and other trash in the suitcase, in addition to the torn papers and five rolls of adhesive tape Sperling had purchased at the airport, but let him pass. The Sperling family spent the weekend seated around their dining-room table taping the SRD back together. By Monday morning, ESTEC had a draft Systems Requirement Document and there was not a piece missing. In actuality, this draft bore little resemblance to the final product, but at least Sperling had a starting document, and he would forever be grateful to Palaoro for that.

Another problem I remember was the size of the NASA teams that participated in the major program reviews in Europe. In previous manned programs, NASA had established a tradition of sending very large teams of experts from its field centers to the contractor facilities for major reviews. Now, in Spacelab, we were faced with three-step reviews (NASA, ESA, ERNO), and expensive overseas travel. On the other hand, it was essential that NASA participate effectively in these reviews because they would be our main conduit for information flow in the program.

When ESRO first realized the size of the proposed NASA teams, it reacted with alarm. The NASA teams could overwhelm the smaller government and industry teams in Europe. After much discussion and negotiating with ESRO and with our own NASA management, reasonable compromises were reached. On at least one review we attempted to use a charter flight to reduce travel costs, but this proved to be too inflexible to suit our changing needs. I am sure our European friends would have been much happier with smaller NASA groups, but on balance, I have to conclude that our representation was about right in order to provide the necessary technical expertise and management oversight. In some cases, NASA individuals who participated in these reviews risked their careers to provide support to the Spacelab program. At JSC, for example, Spacelab was considered of secondary importance and some of the leadership there doubted whether the system could ever work.

The approach taken in the major Spacelab program reviews, with technical experts writing thousands of RIDs and with teams, preboards, and boards reviewing the RIDs and providing disposition, had been well-established in previous NASA programs and was really forced on the European team by NASA. There are those on both sides who feel there may be better schemes for assessing the readiness of requirements, design, and hardware elements. Nevertheless, the system, though cumbersome, has been proven to work. By its very systematic nature its guarantees that thorough assessment will be made at each major milestone of the program and that corrective actions will be taken as required.

Another requirement of this early phase was the need to brief people about the new unique Spacelab program. In addition to briefing NASA higher management and outside groups, I was occasionally called on to brief congressional committees and their staffs. Unless one has had this opportunity or attended a congressional hearing, this experience can come as a complete shock. At most hearings, contrary to the image gained from watching crowded hearings on TV, the witnesses outnumber the committee members present. The audience usually consists of a trade publication journalist, a visiting high school group, several Washington representatives from the aerospace companies, and perhaps some family members of the witnesses. Although Spacelab has always received strong congressional support (after all, most of the cost was being borne by Europe), I found it very discouraging to prepare for these occasions, only to participate in what could best be described as a questionable exercise.

One briefing which did give me a special thrill was a presentation I made to Jacques Cousteau, the noted French oceanographer and host of TV specials. Cousteau displayed a strong interest in our plans for Spacelab and expressed his desire to conduct a Spacelab oceanographic mission some day.

5 Planning For Spacelab Use 1973-1977

While the Spacelab program was focusing its primary efforts on refinements to the basic spacecraft concept, various activities under way both within and outside the program would determine Spacelab's scientific use. This chapter highlights these activities.

EARLY INPUTS

The earliest concepts for Spacelab had envisioned using ground laboratory instruments on board to reduce the costs of space experimentation. In 1970 a Beckman Instruments Company study assessed the feasibility of using commercial laboratory instruments in the similar Space Station environment. Using manufacturers' data and the company's expertise, the study examined 24 categories of instruments from audiometers to X-ray spectrometers with respect to applications, logistics, operation, safety, modifications, and availability. The study verified the desirability of using such equipment in terms of cost savings, reduced lead time, and familiarity of use. The actual feasibility of use required a more detailed study.

On December 10, 1973, Beckman reported the results of a subsequent study to identify problems in using specific off-the-shelf commercial instruments in support of Sortie Lab experiments. Four instruments were selected to typify the primary instrument categories expected to be flown: the Hewlett-Packard Model 45 Calculator, the Fluke Model 8200 A Digital Voltmeter, the Tekronix Model 485 Oscilloscope, and the Beckman Model 24 Spectrophotometer.

A major concern was the possibility of offgassing either hazardous chemicals or at concentrations above safe levels. Tests showed neither threat to exist with the instruments selected. (In any case, later Spacelab planning incorporated an atmospheric scrubber to remove dangerous products from the pressurized environment.) Thermal tests showed that operation in a zero-g environment would cause loss of natural convection cooling and therefore in some cases either instrument modification or supplemental cooling would be necessary. Evaluation of electrical and mechanical design showed that only minor modification would be needed to meet normal Sortie Lab operating conditions. Hazardous conditions or instrument failure could occur from extreme conditions such as loss of pressure or 100 percent relative humidity.

In general, the study was optimistic about the use of commercial instruments in flight, with the possible exception being the need for qualification tests in areas such as electromagnetic interference. It would be interesting to see whether the stringent requirements for materials identification and qualification testing for manned space flight were so ingrained in the system that even the shirtsleeve environment of the Shuttle/Sortie Lab would not be exempt from traditional qualification procedures. A slight dent in the protective armor had been made by the use of a Hasselblad camera in the Apollo missions, but substantial cost savings could only be achieved by increased use of ground laboratory equipment.

Other ideas for Spacelab use were provided during July 1-14, 1974, when the Space Applications Board of the National Academy of Engineering conducted a summer study at Snowmass, Colorado. This was a follow-up to the 1973 Woods Hole Summer Study conducted by the National Academy of Sciences. Led by the NASA Office of Applications, the 1974 study included participants from Europe (ESRO) as well as from the Shuttle and Spacelab programs. The study was headed by Jack M. Campbell, former governor of New Mexico and at the time director of a federation of Rocky Mountain states. The stated purpose of the study was to define an applications program and priorities for the 1980s and to assess the influence of the Shuttle (and Spacelab) on the applications program. The unstated purpose of the study was to determine how to sell an applications program. To that end, the following panels were formed:

Weather and Climate
Communications
Land Use Planning
Agricultural Resources
Inland Water Resources
Extractive Resources
Environmental Quality
Marine and Maritime Uses
Materials Processing
Institutional Arrangements
Costs and Benefits
Space Transportation
Information Services and Processing

The first nine panels were user oriented, aimed at contemporary, emerging, and future applications of space. The remaining four were interactive panels that examined socioeconomic benefits, implementation plans, and influences relative to the Space Transportation System. It is interesting to note that the European users had already held a Space Processing Symposium in March at Frascati, Italy. Europe's strong interest in this potentially profitable area was plainly evident.

The panels at Snowmass varied in amount of space program experience and imagination. It was often difficult to get them to think beyond the current state of the art and their own experience. Nevertheless, by the end the panels had provided a smorgasbord of recommendations for space applications and for utilizing the new Space Transportation System, including the planned Spacelab. Materials processing was recommended as a particular area in which space experiments could be flown as a payload of opportunity (not being orbit- or time-critical) to help keep Shuttle load factors high and lower the operational costs. An interesting output from the socioeconomic panels was the conclusion that NASA was not the proper organization to interface with the applications users and customers. The panels envisioned some kind of intermediary organization with strong skills in marketing.

MISSION SIMULATIONS

Even before the Spacelab agreements were signed, another activity under way would have considerable impact on Spacelab's potential use. This effort had the unwieldy name of Concept Verification Test (CVT). It started as an outgrowth of Space Station studies to demonstrate the effectiveness of various system, subsystem, and operational concepts. As early as July 25, 1973, an electrical breadboard had been assembled to simulate high-data-rate experiments emphasizing data compression techniques including data interaction and onboard processing. This extensive effort was led by William Brooksbank at Marshall Space Flight Center, and for the next several years it was a supporting effort to various mainstream study and definition activities. Brooksbank organized an intercenter coordination group to provide broad participation in the tests, with representation from Ames, Langley, and Lewis research centers and from the other manned space flight centers, KSC and JSC.

By January 1974 a general purpose laboratory, much like a Space Station or Spacelab module, had been added to the CVT complex at Marshall (fig. 37), (where experiments were conducted in ionospheric disturbances, atmospheric cloud physics, metal alloy preparation, high-energy astronomy, and superfluid helium. All involved real-time interaction between the experiment and the Principal Investigator. The high-energy astronomy experiment was located on a simulated pallet, with control equipment in the laboratory. These simulations received the attention of congressional and top NASA officials, and results were made available to the ESRO team for use in its Spacelab planning. Other NASA centers and the Shuttle Payload Planning Working Group chairmen proposed new experiments for simulation. Soon it was suggested that the general purpose laboratory be upgraded to make it more like the Spacelab design. A Preliminary Requirements Review for

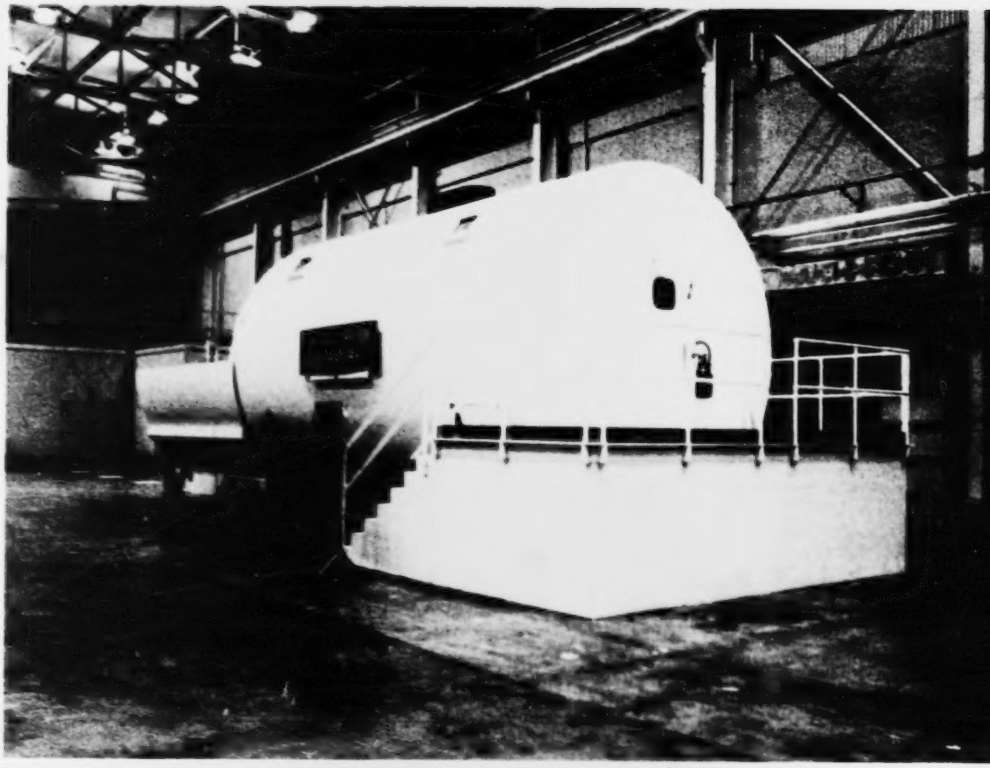


Figure 37. General purpose laboratory used in the Concept Verification Test program at Marshall Space Flight Center.

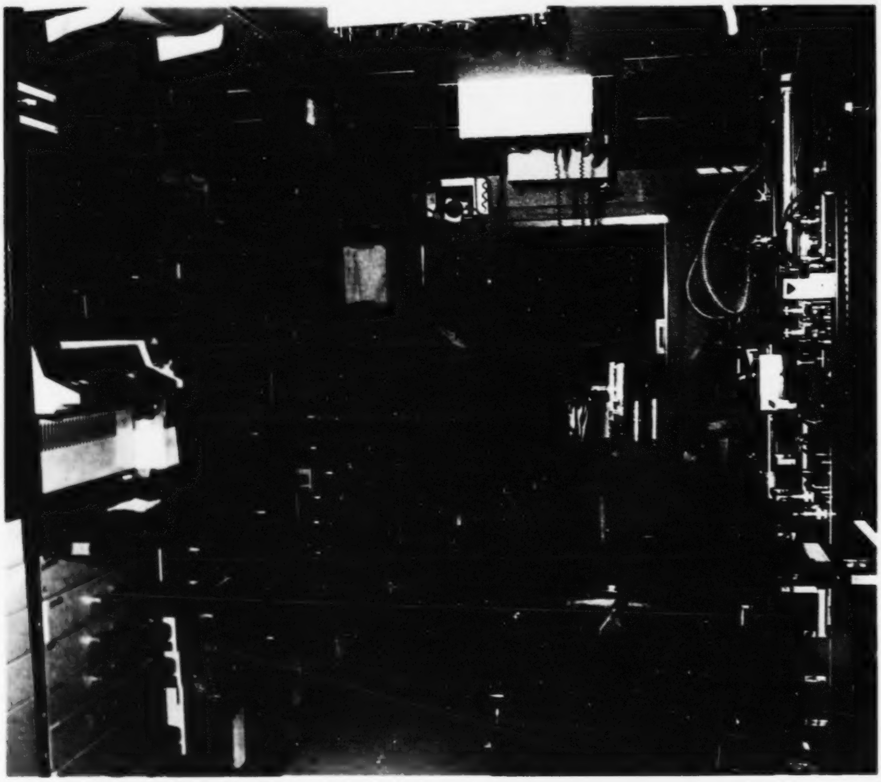
the improved simulator was held May 29-30, 1974, with plans for its completion by mid-1976. Already, 37 Principal Investigators had participated in the first two demonstration test runs in the existing simulator.

An integrated life science mission was conducted in the CVT facility July 15-19, 1974. Planned and conducted by Ames Research Center scientists, this test demonstrated candidate experiment protocols, modular organism housing units, and rack-mounted equipment plus radioisotope tracer techniques. Principal Investigators from several universities utilized 5 monkeys, 12 rodents, 2 chickens, and 20 marigold seedlings in the test. This mission was followed in December 1974 by a 5-day mission with 11 materials science experiments. This test received much favorable attention, and it appeared that the CVT program was set for a long run.

As further evidence that CVT was expected to be a permanent facility, the Preliminary Design Review was conducted on the Spacelab simulator, the Shuttle interface simulator, and the data management simulator, all elements of an expanded CVT effort, in mid-May, 1975. By June 30, the data management simulator was demonstrated in two parts: the multifunction display and the data bus, including the digital interface unit and the computer interface unit; and the SUMC advanced technology computer with its input-outputs units.

Another test (number 5) was conducted during the week of August 10 (fig. 38). This multidisciplinary, multicenter mission produced useful information in areas of hardware standardization, crew training, communications requirements, and procedures for handling equipment failures. The suitability of using onboard minicomputers by the onboard crew was clearly demonstrated, as was the cross-training of scientific crew members for intra- and interdisciplinary experiments. Direct communication between the investigator and onboard scientists improved data interpretation and facilitated the repair of experiment equipment.

Figure 38. Interior of the general purpose laboratory for Concept Verification Test number 5 conducted in August 1975.



Although it would seem that the future of the CVT program up to this point was optimistic, such was not the case. Most of the experiments used for the simulations were under development by NASA's various payload offices, but funding for the actual test missions was provided by the Office of Manned Space Flight. In April 1975 Deputy Associate Administrator Naugle had sent a memo to the Associate Administrators for Science (Noel Hinners), Applications (Charles Mathews), Manned Space Flight (John Yardley), and Aeronautics and Space Technology (Alan Lovelace), asking if they needed the CVT simulations and would provide funding within their budgets for further tests. By June, all four program offices had replied in a negative manner. Even the Office of Life Sciences, then located in the Office of Manned Space Flight, felt it had gained sufficient insight from the completed and planned simulations that it could proceed with planning Spacelab life sciences payloads without CVT use in fiscal year 1977 and beyond.

Thus CVT was doomed. Given the urgency of funding for Shuttle development, the Office of Manned Space Flight had no alternative but to salvage what it could from the program and store the general purpose laboratory for later use, if needed. Two additional simulations were conducted. The first, November 17-21, 1975, was a materials science test to determine how effectively a team of scientists in orbit, with only moderate experiment operations training, could conduct experiments while being monitored on the ground by a team of Principal Investigators using two-way voice and downlink-TV contact. The final simulation on July 15, 1976 employed a high-energy cosmic ray balloon flight experiment. With this demonstration, CVT was concluded. Although it had provided very useful information and operational experience, the program fell victim to the vagaries of organizational and budgetary life.

During the same time as the CVT simulations, another program was established to take advantage of Ames' Airborne Science Program using the Convair 990 aircraft. Discussions of such a program had been under way since the beginning of the Spacelab program, and soon representatives of NASA and ESRO were flying on Convair 990 missions as observers and considering whether simulated Spacelab missions would add significantly to planning for early Spacelab payloads. From 1972 to 1974 four relatively simple simulations were conducted aboard the Ames Learjet and a more complex mission aboard the CV 990. Each mission was designed to evaluate potential Shuttle/Spacelab concepts in increasing detail. The first four missions studied payload operation by members of a Principal Investigator team associated with each experiment. The last mission explored experiment operation by a limited number of carefully selected experiment operators (Payload Specialists).

At the ninth meeting of the Joint Spacelab Working Group on March 19, 1974, Dr. Ortner of ESRO proposed a joint ESRO/NASA program called the Airborne Science/Spacelab Experiments System Simulation (ASSESS). Dr. Dai Shapland and Jan de Waard would head ESRO participation and Bob Lovelett and Gus D'Onofrio from NASA Headquarters, Don Mulholland from Ames, Lee Weaver from MSFC, and astronaut Joe Allen from JSC would provide NASA leadership. A mission planning group was already in existence, and ESRO had issued an Announcement of

Flight Opportunity to obtain suitable European experiments. By May, it was agreed that a joint mission could be authorized under the umbrella of the Spacelab Memorandum of Understanding by a simple exchange of letters between the two Program Directors. ESRO kept the pressure on NASA, and by August an exchange of letters between myself and Heinz Stoewer (then ESRO Acting Program Director) did take place.

My August 8 letter to Stoewer projected a joint mission in 1975 to draw Spacelab design conclusions, study operational concepts, and perform scientific experiments. NASA would select its own experiments, provide and operate the CV 990 airplane, provide experiment support equipment, provide laboratory space for ESRO-sponsored experiments, integrate and support the selected experiments, and install all mechanical equipment in the airplane. For its part, ESRO was to select, integrate, and support its experiments. Each agency was to bear its respective costs, data would be fully shared, and data on the operational simulation of the Spacelab mission would be jointly published. Stoewer's confirmation letter of August 26 stated full agreement with my proposal but cautioned that ESRO's funding limit for the first mission was 350,000 accounting units (appoximately $440,000 at the time).

By the end of 1974, planning for the first ASSESS mission was taking shape. Complementary experiments in infrared astronomy and upper atmospheric physics had been selected by ESRO and NASA. The experiment operators, two from Europe and two from the U.S. plus a backup operator, included experienced airborne astronomers, a science-trained astronaut, a doctoral graduate student, and an engineer. This group was chosen to reflect the backgrounds of expected Spacelab science crews. A series of five flights on consecutive days would approximate the useful time of a 7-day Spacelab mission. Since the experiments were "real," 2 weeks of flights for the Principal Investigators was scheduled following the week of Spacelab mission simulation flights to assure achievement of the scientific objectives of the experiments.

The simulation flights were conducted, and the program was successfully completed at Ames Research Center on June 7, 1975. The international crew of five completed a 6-day mission on board the CV 990 *Galileo II*, living in special quarters adjacent to the area where the aircraft was parked between flights (fig. 39). The Ames Mission Manager and Flight Director was Louis Haughney. The European experiment operators were Dr. John E. Beckman of Queen Mary College in London and Nicholas Wells, a graduate student at the University of Sussex. The U.S. experiment operators were Dr. Robert A. Parker, a NASA astronaut and later a crew member on the first Spacelab mission, and Dr. Kenneth A. Dick from the University of Maryland. Infrared observations of the Earth's upper atmosphere, Venus, stars, and other celestial features and ultraviolet measurements of planetary atmospheres were made. The Principal Investigators for these experiments came from Meudon Observatory near Paris, Groningen University in the Netherlands, Queen Mary College, the University of Southampton in England, the Jet Propulsion Laboratory in Pasadena, California, the University of New Mexico, the University of Colorado, and Ames Research Center.

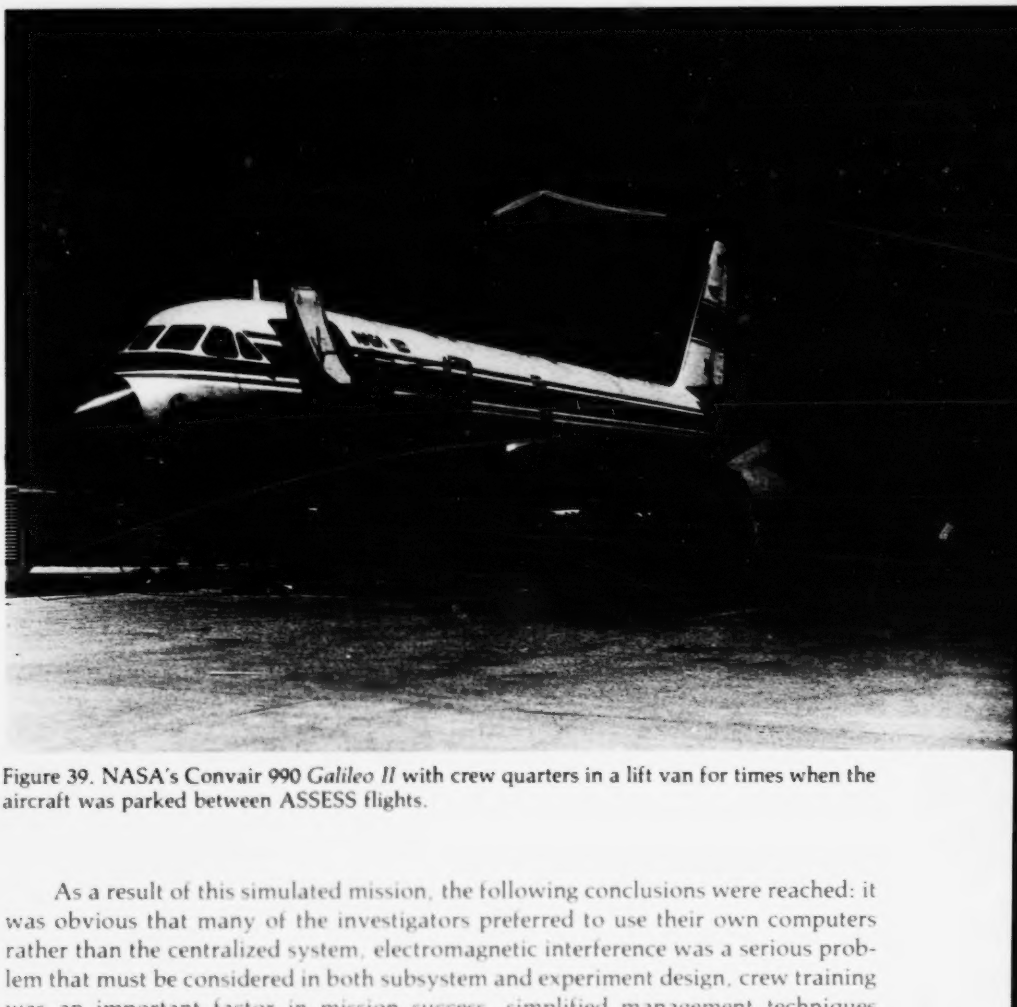


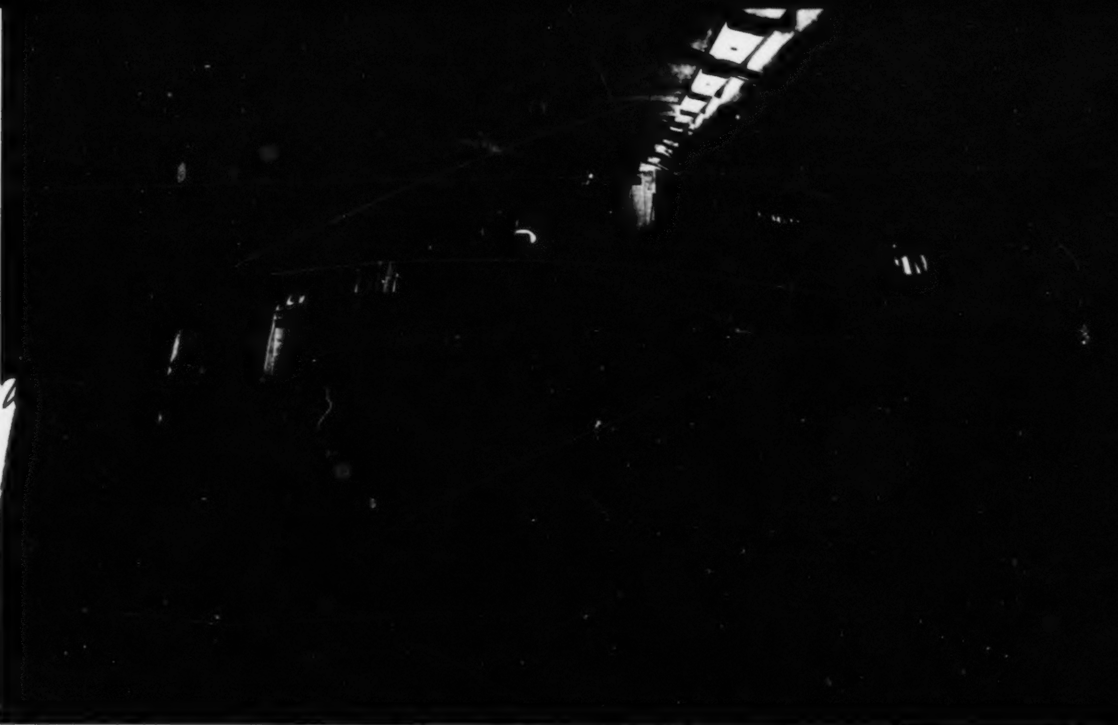
Figure 39. NASA's Convair 990 *Galileo II* with crew quarters in a lift van for times when the aircraft was parked between ASSESS flights.

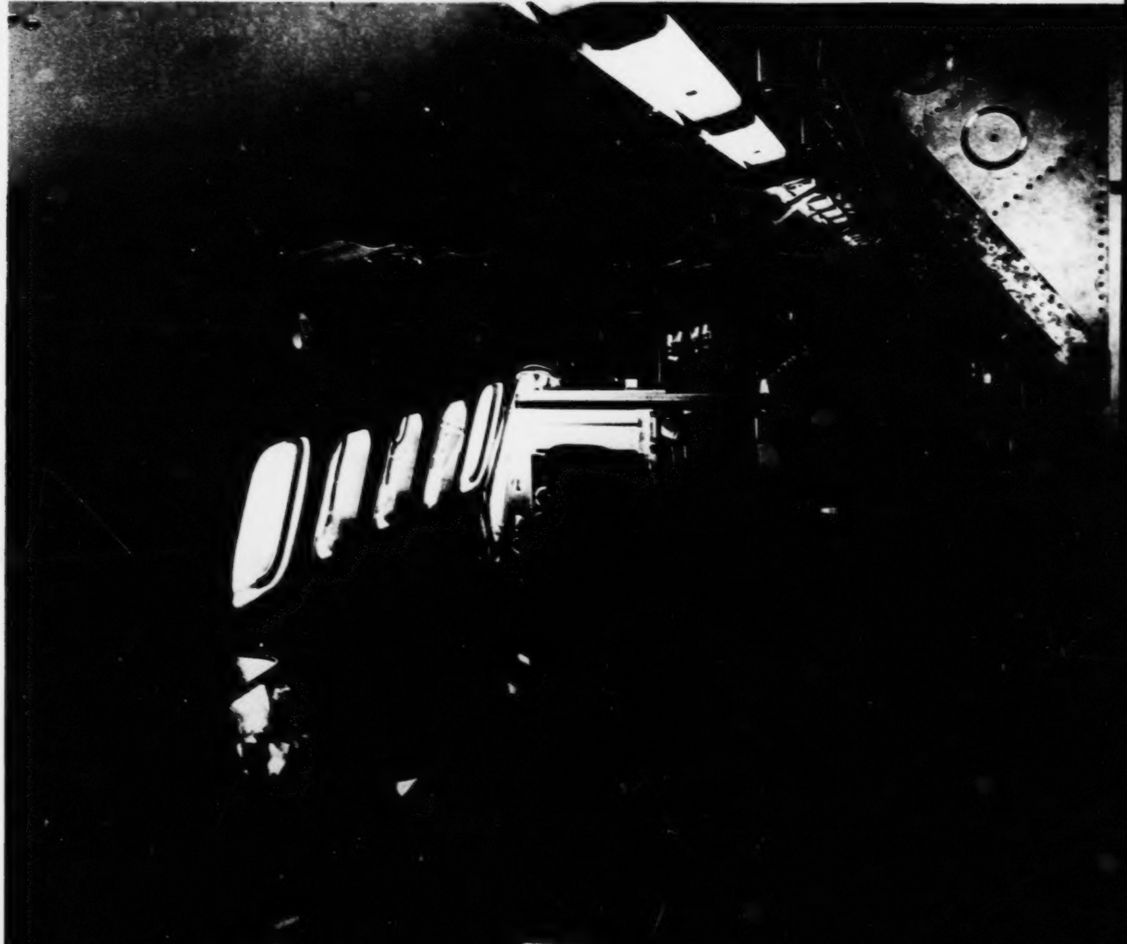
As a result of this simulated mission, the following conclusions were reached: it was obvious that many of the investigators preferred to use their own computers rather than the centralized system, electromagnetic interference was a serious problem that must be considered in both subsystem and experiment design, crew training was an important factor in mission success, simplified management techniques reduced program costs, and real-time contact between the Principal Investigator and the experiment operator on board must be controlled. All in all, it was a very inexpensive and effective mission simulation, at least in part because of the excellent cooperation among ESRO, NASA, and all the participants.

By August 1975 our European partner (now ESA) was already arguing for further ASSESS missions. NASA was reluctant, feeling it had already recognized the major lessons to be learned from airborne simulations. The ongoing saga of the CVT program and our inability to secure supporting funding from the various program offices for mission simulations were also fresh in our minds. Nonetheless, initial approval was obtained late in 1975 to conduct ASSESS II as a joint mission sponsored by the NASA Office of Applications and Office of Space Flight and by ESA. Final approval was obtained in March 1976 and "launch" occurred 14 months later on May 16, 1977. For this mission, emphasis was placed on development and exercise of management techniques planned for Spacelab using management participants from NASA and ESA who would have responsibilities for the Spacelab 1 mission, then scheduled for 1980. Thus, representatives from JSC would handle the flight operations, representatives from KSC would handle the "launch" site operations, and a Mission Manager (analogous to a Payload Manager) was selected from MSFC. In addition, ESA's new payload integration organization, (SPICE), would handle experiment integration and coordination activities for the European part of the payload. ASSESS II was also NASA's first attempt to identify and assign a Mission Specialist to serve in a Spacelab-type activity (fig. 40).

Many participants were involved in ASSESS II because of its diverse objectives. Headquarters oversight was provided by Bernard Nolan and William Armstrong from NASA and Dai Shapland from ESA. Dr. Karl Henize, a NASA astronaut (later assigned to the Spacelab 2 crew), served as Mission Specialist. The Payload Specialists were chosen from a pool that included David Billiu and Robert Menzies of JPL and Lee Weaver of MSFC, all nominated by NASA, and Claude Nicollier (later an ESA career astronaut), Jurgen Fein, Klaus Kramp, and Michael Taylor, all selected by ESA. Jan de Waard of SPICE served as the Mission Manager for ESA and Carlos Hagood and Stanley Reinartz divided that responsibility for NASA. Other key performers for ESA were John Beckman, Hans Hamacher, Josef Schmitt, Helmut Brucker, and Hugh Hopkins, who were assigned as Mission Scientist, Chief Engineer, Ground Operations Manager, Payload Integration Operator, and Payload Operations Control Center Operator, respectively. On the NASA side, similar support was provided by Anthony Deloach, Roy Lester, Tony O'Neil, and Clark Owen, all from Marshall, as Mission Scientist, Payload Operations Manager, Ground Operations Manager, and Payload Operations Control Center Manager, respectively. In addition to Mission Specialist Henize, JSC provided Gerald Griffith as Flight Operations Manager and John Whiteley as Mission Control Center Manager. KSC provided Randall Tilley as the Launch Site Ground Operations Manager. Ames Research Center, in addition to its usual Airborne Science Program operations support, supplied Donald Anderson as its Mission Manager, John Reller as Ground Operations Manger, Robert Cameron as Mission Coordinator, and Carr Neel as ASSESS Program Manager. Although these were the key people from the Spacelab viewpoint, a strong cadre of dedicated Principal Investigators provided meaningful experiments for the simulated mission and many other individuals played supporting roles in the ASSESS II operation and documentation.

Nine aircraft flights were flown over 10 consecutive days to simulate a total Spacelab mission. The payload flight crew, consisting of four Payload Specialists and one Mission Specialist, were confined to the aircraft and the attached living quarters for the entire period except for brief moments. As in the previous simulation, a considerable amount of "real" scientific data were obtained. From the Spacelab viewpoint, however, the most significant results were lessons that applied to Spacelab operational planning. Too numerous to list, they covered such important areas as payload selection and funding, management relations, preflight planning, payload integration, documentation, analytical integration, European





payload integration, launch site processing, safety, flight crew makeup, selection, training, scheduling, flight/ground operations, and data handling. With the completion of this mission, the ASSESS program was brought to a close. In retrospect, it is probably fair to say that the program was considerably more important to the European participants than to those from the U.S. because of the European team's lower level of experience in manned space activities. More importantly, ASSESS II in particular proved to be an accurate foretaste of the Spacelab 1 mission.

REAL MISSION PLANNING

Meanwhile, the first Spacelab mission and its payload became the subjects of serious discussions. In early 1974, the Joint User Requirements Group began informal discussions of the mission. The Joint Spacelab Working Group expressed its concern over the need to use the first missions to verify the performance of the Spacelab. At its March 19 meeting, it expressed the opinion that the Spacelab program should dictate the configuration to be flown and specify what resources would be available for experiments. At this time no decision had been made as to who would develop and fund the verification flight instrumentation (VFI) and when it would be installed in the Spacelab. As a first cut, the working group established the following preliminary guidelines: the first mission would have a long module and a pallet of two segments; 3000-4000 kg of weight, 1.5-2.5 kw of electrical power, and approximately 100-150 hours of crew time would be available for experiment activities; and the first mission would be no longer than 7 days. These guidelines were established so that the planning group for the first Spacelab mission could look for payloads compatible with VFI requirements for weight, power, and crew time. The basic Spacelab configurations available for early mission planning are shown in figure 41. A module plus two-pallet configuration as envisioned in 1974 is shown in figure 42.

On April 23, 1974 the NASA/ESRO Joint Planning Group, co-chaired by Dr. Gerald Sharp of NASA and Jacques Collet of ESRO, met to develop guidelines and procedures for selection of the first Spacelab payload. The group recommended the following guidelines for payload selection:

(1) The payload should be complementary, consistent with future Spacelab missions.

Figure 40. Top: forward view of the *Galileo II* interior as configured for the ASSESS II simulation. Bottom: aft view of the interior, with Payload Specialist consoles at right and Mission Specialist station at left.

(2) The payload should be open to science, applications, and technology experiments.
(3) The experiments should take advantage of Spacelab's unique capabilities.
(4) The experiments should capitalize on man's presence.
(5) The payload should demonstrate Spacelab's uniqueness and its broad potential.
(6) Payload crew selection and training should permit the evaluation of future selection and training criteria.
(7) The payload should not require full use of crew time and resources.
(8) NASA/ESRO interfaces should be kept simple.

On procedures for payload selection the group recommended the following:

(1) Joint ESRO/NASA planning.
(2) Open solicitation of experiments on both sides.
(3) Experiment selection on the basis of merit.
(4) Guidelines (above) to form basis for selection criteria.
(5) Proposals selected to be funded by respective sides.
(6) Final experiment complement to be jointly determined.
(7) Selection of European crew member to be addressed separately.

The group quickly concluded that a more detailed list of constraints was necessary before substantive planning could proceed and requested the Joint Spacelab Working Group (JSLWG) to develop such guidelines. NASA presented an expanded set of constraints for consideration at the next JSLWG meeting on May 17, including a number of constraints imposed by the Shuttle, one of which was a total of only four to five crew members for the first Spacelab mission if it was conducted, as then planned, on the seventh Shuttle flight. This would be the first operational flight after six test missions. ESRO took the new constraints under advisement, but was particularly concerned about the restricted crew size and the requirement to deliver prototype experiments to NASA/MSFC 16 months prior to flight.

The preliminary guidelines, procedures, constraints, and a planning timetable were presented to ESRO Director General Hocker and NASA Administrator Fletcher at their first annual review of the Spacelab program on May 20. This meeting was the same one in which ESRO's recommendation to move forward with the ERNO contract went awry because of the problem of insufficient weight margins. Nevertheless, the two agency heads did find time to approve the general approach being taken by the Joint Planning Group.

The Joint Planning Group met again on September 23. ESRO reported that a call for Spacelab utilization ideas sent out in June had elicited 241 replies, over half of which were new "customers" for space experimentation. The group agreed to work toward agreement on the experiment objectives by December while continuing to study the emerging VFI requirements. On December 11, the group held its final meeting with the understanding that this ad hoc organization was no longer needed;

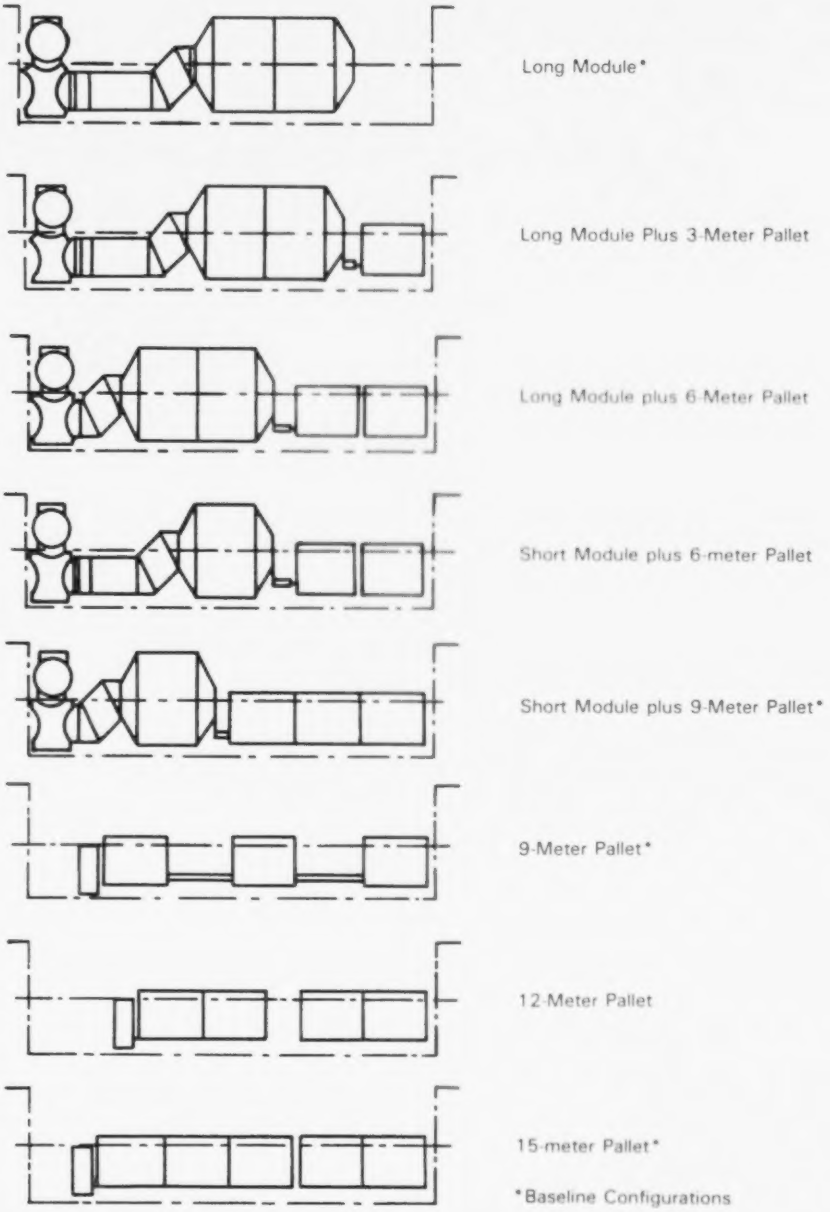

Long Module*
Long Module Plus 3-Meter Pallet
Long Module plus 6-Meter Pallet
Short Module plus 6-meter Pallet
Short Module plus 9-Meter Pallet*
9-Meter Pallet*
12-Meter Pallet
15-meter Pallet*
*Baseline Configurations

Figure 41. Basic Spacelab flight configuration available for early mission planning.

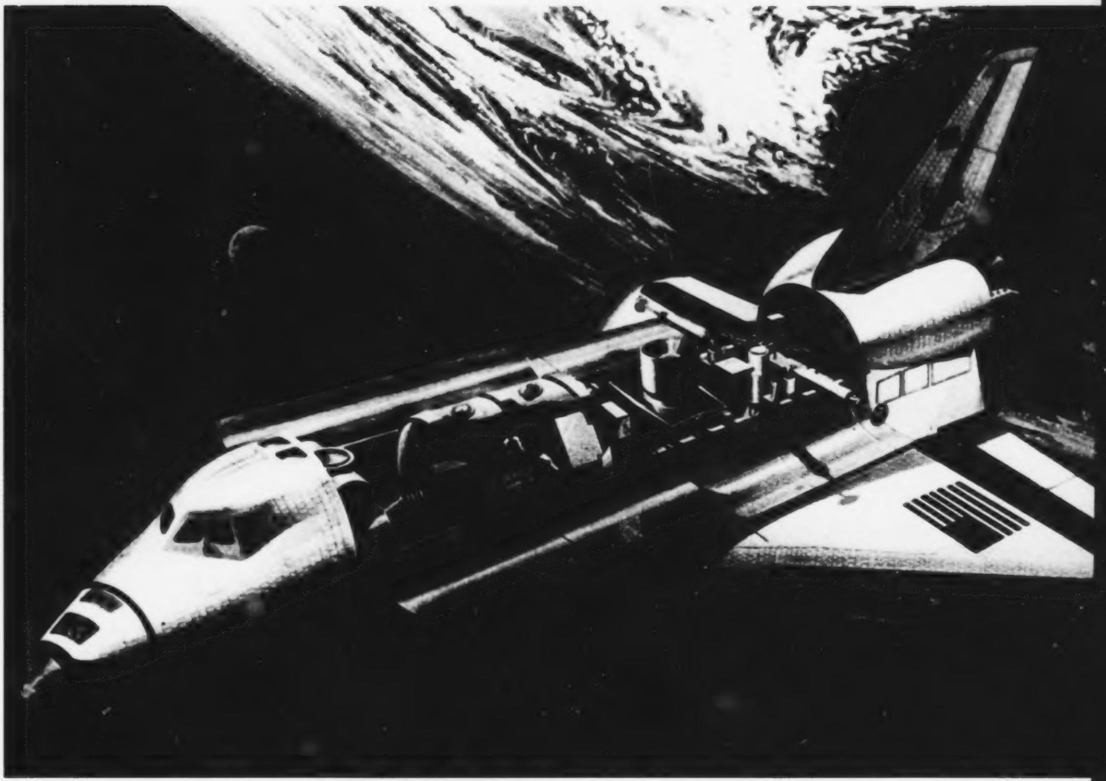


Figure 42. Artist's rendering of a Spacelab module plus two-pallet configuration in the Orbiter cargo bay, carrying a hypothetical payload.

its functions would be assumed by line payload organizations. (As seen later, this dissolution was premature and unofficial until action was taken by the agency heads some months later.) The group established a jointly recommended set of experimental objectives (multidisciplinary) for submittal to the respective agency managements for review and approval.

In the meantime, the JSLWG continued to expand the list of constraints on the first payload. By July 1974, a list of 14 points had been approved by the NASA Manned Space Flight Management Council. The configuration now stated a one- or two-segment pallet with the long module. Weight and power were unchanged, but the crew size was to be "minimized" and "up to" 100 man-hours would be available for experiment operations. Other constraints were restricted operations with the

Tracking and Data Relay Satellite System (TDRSS), no command functions from Europe, maximized onboard data recording and minimized real-time transmission, no extravehicular activities (EVA), no Orbiter manipulator, no Instrument Pointing System (IPS), no access to Spacelab when in vertical position (up to 9 days prior to flight), no access to pallet after Orbiter doors were closed, and postflight access to payload as late as 30 hours after landing.

At their next meeting in September, JSLWG members started to talk about the constraints for the second Spacelab mission, the most important one being that it would not be a joint payload. This point reflected the guidance of NASA Administrator Fletcher. ESRO was not ready to agree to this point. NASA also suggested at this meeting that the first Spacelab mission might be replaced by a DOD mission on the first Shuttle operational flight. ESRO objected strongly to this proposal. Even though ESRO had been quick to accept a possible 6-month delay in the Spacelab schedule attendant with a recent delay in the Shuttle development schedule, any proposal to remove Spacelab from the first operational mission, as had been specified in the Memorandum of Understanding, was clearly unacceptable.

By the March 1975 JSWLG meeting, the nominal parameters of the first mission were presented, and users expressed their desire for a reduction in orbital altitude from the proposed value of 470 km. The VFI requirements were driving the launch time, altitude, Sun angle, and hot and cold exposure time in order to test the Spacelab systems as much as possible. At this meeting the decision was made to carry only one pallet segment with the long module.

The preliminary guidelines for the second Spacelab flight now listed 10 items: a pallet-only mode, 7000 to 8000 kg of experimental weight, 4 to 5 kw of electrical power for experiments, two or three Payload Specialists, a 7-day mission with "up to" 100 man-hours available for experiment operations, full data transmission capability through TDRSS, EVA as required by the payload, Orbiter manipulator available, IPS availability to be determined, and planned pallet access before and after flight in the Orbiter Processing Facility only. This second mission would be very ambitious, with experiment resources considerably beyond those provided for the first mission.

It was now time for the two agencies' top management to approve the approach to the first mission. At the annual review of the Spacelab program on June 4, 1975, Roy Gibson, now Director General of ESA, and NASA Administrator Fletcher commented and took action on a number of items, among which was that the objectives for the first Spacelab payload as presented by the Joint Planning Group were accepted and the group formally dissolved.

The proposed objectives of the first Spacelab mission were as follows:

(1) Investigate fundamental science in vapor, liquid, and solid phase interaction under gravity-free conditions.
(2) Investigate the near-Earth environment by performing active and interactive experiments on and in the Earth's atmosphere and magnetosphere.
(3) Investigate the effect of the space environment on body fluid redistribution,

vestibular function, growth, development, and organization in living systems.
(4) Monitor the atmosphere and its effect on environmental quality.
(5) Observe and monitor the Earth's surface.
(6) Observe extended sources of radiation in the visible, ultraviolet, and infrared spectra too faint for Earth-based observations.
(7) Demonstrate the capability of Spacelab as a technology development and test facility.
(8) Conduct communications investigations that will provide a basis for the efficient utilization of orbital spacing and frequency spectrum.

Thus the first Spacelab payload would have multidisciplinary objectives to demonstrate to all potential users the effectiveness of the Spacelab system. Gerry Sharp presented a series of recommended actions toward payload management and mission planning for the first Spacelab flight, which were accepted. NASA and ESA were to designate co-chairmen and members of a Joint Program Integration Committee for the first Spacelab payload. NASA took the possibility of a cooperative plan for the second Spacelab payload under advisement.

The Director General and Administrator had spoken. Unfortunately, NASA was not ready to move because it had not yet decided on how to manage its Spacelab payloads. John Yardley, for example, encouraged by Phil Culbertson, Director of Mission and Payload Integration, objected to the Associate Administrator about many of Sharp's recommendations. In a June 27 memo, Yardley questioned the proposed experimental objectives, the function of the Joint Program Integration Committee and its supporting Joint Project Integration Team, the establishment of a Director of Spacelab Payload Programs, the definition of payload and discipline interfaces by committee, and the lack of plans for compatibility analyses on proposed experiments. At this time, Culbertson was soon to become the payload planner for all Shuttle missions as the Assistant Administrator for Planning and Program Integration, so his particular interest in Spacelab payload planning was understandable.

The Joint Program Integration Committee (JPIC) did not meet until November 18-19, 1975. By this time Robert Kennedy had been appointed NASA Payload Program Manager for Spacelab flights 1 and 2 within the Office of Space Science and would be NASA co-chairman of JPIC. He was supported at this meeting by Dr. Sharp (Science), Dr. Rufus Hessberg (Life Science), Dr. Dudley McConnell (Applications), and Bob Lohman (Director of Engineering and Operations in the Spacelab Program Office). Jacques Collet was again the ESA co-chairman and was assisted by Erik Peytremann, M. Fournet, Dr. Gunther Seibert, and Dr. Dai Shapland. At its first meeting the JPIC reviewed preliminary management plans for the first mission, Level I constraints and Level II guidelines imposed by the system and verification test requirements, and payload accommodation study results and plans. Although it would appear that JPIC had picked up where the Joint Planning Group had left off, with one committee replacing the other, it was soon apparent that this was not the case. NASA's establishment of a Spacelab payload management function under Kennedy meant that his office, not any committee, nor Culbertson's office, would be responsible for future NASA Spacelab payload planning. Culbertson's organization, after some months of sparring with the Science and Applications Program Offices, was dismantled, and Culbertson was reassigned as Special Assistant to the Administrator for the Space Transportation System. The members of his team were assigned to the payload planning groups under Kennedy (for Space Science) and Dr. Charles Pellerin (for Applications). Culbertson later was selected as the first NASA Associate Administrator for Space Station planning and subsequently assigned to the new post of General Manager after the Shuttle *Challenger* tragedy in 1986.

PAYLOAD MANAGEMENT

In the midst of all these activities, one particular meeting stands out. On March 20, 1975 a presentation was made to the NASA Associate Administrator, Rocco Petrone, by Luther Powell, Deputy Spacelab Program Manager at MSFC. This was scheduled after the Spacelab Preliminary Requirements Review (PRR) to summarize, at Petrone's request, users' requests for changes to Spacelab, the activities of the avionics working group, and plans for PRR closeout. A number of issues related to user requirements were highlighted: a film vault would not be provided by the Spacelab program but would have to be provided, as needed, by users; the Spacelab Program Office would investigate concerns expressed about the complexity of the scientific airlock; a forward viewport and additional feedthrough for experimenters was rejected; remote control of the Orbiter closed-circuit TV from the Spacelab was rejected; lower temperature cold plate capability on the pallet was rejected; the program office would investigate concerns expressed over the operational complexity for prelaunch and pre-reentry chilldown of the module to provide a thermal heat sink; and video tape recorders in the Orbiter were rejected. These program office positions were controversial but were accepted by Petrone. Apparently he agreed that a halt had to be called to the program additions being made in response to the many user requests.

NASA's management approach for Spacelab payloads was not yet settled either. In its preliminary management plan dated November 5, 1975, the Office of Space Science (OSS) set out its plan for the Spacelab 1 and 2 payloads, based on its responsibility for management and development given by the Associate Administrator by memo dated September 22, 1975. Dr. Noel Hinners, the Associate Administrator for Space Science, had assigned the responsibility to the OSS solar terrestrial program under Dr. Harold Glaser and Floyd Roberson, and within their program office Bob Kennedy was named Manager of the Spacelab payloads program. The management plan set out the following precepts:

(1) Payload responsibility for Spacelab 1 and 2 was with the Office of Space Science.
(2) Concept verification responsibility for the Spacelab system was with the Associate Administrator for Space Flight.
(3) Spacelab 1 was to be a joint NASA/ESA mission.
(4) Spacelab 2 was to be a U.S. pallet-only mission.
(5) The Announcement of Opportunity process was to be used.
(6) Three NASA program offices (Space Science, Applications, and Aeronautics and Space Technology) were to evaluate and recommend NASA experiments.
(7) Selection of the final payload complement was to be made by the Associate Administrator for Space Science.
(8) MSFC was to have payload project management.
(9) JSC was to conduct flight operations.
(10) KSC was to perform Level I, II, and III integration and tests.
(11) Payloads would be designed to a cost limit.
(12) The Payload Program Manager was to define total requirements for information extraction and data analysis.

This plan was a good start but it was sure to receive considerable criticism from various elements within and outside NASA during the next few months, and many significant changes would occur. Nevertheless, a start had been made and soon payload management by committee would be a thing of the past. A line organization had been established to direct this important facet of the Spacelab program.

One significant modification was reflected in Yardley's memo to KSC and MSFC on December 15, 1975, clarifying the Level III integration responsibilities for the mainline Spacelab effort. As in the case of payload integration, a delineation had to be made between "hands-on" and "hands-off" activities, the latter including analytical integration, sustaining engineering, logistics, and follow-on procurement. The "hands-off" activities would remain the responsibility of MSFC.

Although the Office of Space Flight (Yardley) and the Office of Space Science (Hinners) continued to have differences of opinion about the management plan, the difficulties were gradually worked out. By February 1976 the number of major issues had diminished to four: assuring that the verification flight test requirements were compatible with the experiment requirements; funding for Payload Specialist training, ground and flight software, and data handling; funding for the operation of the Payload Operations Control Center at JSC; and responsibility of MSFC as system integrator. It was obvious that the general plan was workable. That these management problems between Spacelab and its payloads existed throughout the agency is reflected in the fact that it was not until November 1, 1976 that a Mission Implementation Agreement was issued at MSFC. This agreement, signed by O. C. Jean, Manager of the Spacelab Payload Project Office, and Jack Lee, Manager of the Spacelab Program Office, defined their offices' respective responsibilities in implementing the first and second Spacelab missions.

OPERATIONAL CONCERNS

Not only were there concerns about Spacelab payload management. Many people were beginning to ask about the potential costs to NASA of developing an operational capability for the Spacelab. Because of his concerns, John Yardley authorized a Cost Reduction Alternatives Study on April 8, 1975. Aimed at providing input for the upcoming fiscal year 1977 budget discussions, two existing study contracts were extended under the joint sponsorship of my Spacelab Program Office and the Mission and Payload Integration Office under Culbertson. The first two tasks (onboard computer utilization and software integration, and Spacelab and payload integration) were added to a Langley Research Center study under way with Rockwell. Two tasks (operations planning and control and flight crew training) were added to a Johnson Space Center study with TRW. A fifth task, to collect and evaluate all the technical tasks and to support the Spacelab Program Office in developing recommendations, was also given to Rockwell.

Dr. Rodney Johnson, my Director of Experiment Accommodations, was the Study Director, and Fred Allamby and Claiborne Hicks were the Technical Managers at Langley and JSC, respectively. Ralph Hoodless and Carmine De Sanctis of the Spacelab Project Team at MSFC were assigned as Support Managers to the two contracts in order to provide detailed technical knowledge of the current design, access to all the program reports and specialists, and a thorough understanding of the assumptions on which the current planning was based. The principal objective of the study was to analyze Spacelab operating costs and ways in which those costs could be minimized by looking at operations and program alternatives.

Midterm reports on the two study contracts were presented to Yardley on August 26, and redirection to the contractors was given for the remainder of the effort, which was to be concluded by year's end. Final presentations on tasks 1-4 were made on December 9, and a brief summary of the integration task was given to the Office of Space Flight Management Council on January 30, 1976. The results of the study, for the most part, provided no surprises.

The first task was to search for onboard computer configurations, operating approaches, and onground supporting techniques that would reduce the cost per flight and the investment in supporting facility and equipment hardware, software, and personnel. Key to this task was the rapid development of mini- and special-purpose computers, which provoked the general question of centralized versus decentralized computing on board Spacelab. The study concluded that an aggressive program to develop and utilize dedicated experiment microprocessors plus a standard library of computer routines for services would reduce costs to 60 percent of the centralized approach. Nevertheless, because the Spacelab had to provide a single interface to Orbiter avionics, the central computer could not be eliminated. A hybrid of the planned command and data management system and dedicated processors was the recommended route.

The second task was to search for integration approaches that would minimize the investment and recurring costs associated with ground support equipment, transportation, and personnel. It was also to search for approaches to minimize flight hardware changeout, new software development, verification and integration, and checkout duplication. The study focused on Levels III and II of integration and also considered how the engineering model would be used in support of the integration effort. Although the costs of flight hardware, ground support equipment, and facilities were significant, they paled in comparison with manpower costs over the program's lifetime. Thus every effort would have to be made to reduce the size of teams required to check out Spacelab, to support the checkout operations, and to provide sustaining engineering for all flight and support hardware.

The third task provided the first definitive look at Spacelab flight operations. The objective was to search for approaches in operations planning and control that would minimize duplication, reduce the cost per flight, and lessen the investment in supporting facility and equipment hardware, software, and personnel. The payloads were critical to this task because of their impact on mission planning, payload flight operations, real-time replanning during the course of a mission, and experiment data preprocessing. For the first time, the program examined a Payload Operations Control Center, a supplement to the existing Mission Control Center, where the Spacelab and its complement of experiments would be controlled. It was concluded that only "housekeeping" and "snapshot" data up to 1 megabit per second would be required, with wideband data processing deferred to a separate postflight data processing facility. Concepts were developed for providing three categories of support: assistance only—the Payload Specialist operates almost autonomously; minimum command—the Payload Specialist has primary responsibility, but with significant real-time mission monitoring and evaluation on the ground; and full command—the Payload Specialist is essentially an equipment operator, and the ground has primary responsibility for real-time data evaluation and replanning.

The fourth task was to define comprehensive approaches to flight crew training necessary to operate the Spacelab. Although it was recognized that much training could be obtained with the engineering model and flight hardware of the Spacelab itself, the task was to define which integrated and part-task trainers would also be needed. Although the original study plan I submitted to Yardley on April 4, 1975 emphasized that this task would address payload-associated activities, by the time the final presentation was made on January 30, 1976, it was clear that the study pertained solely to Spacelab subsystem operations; training related to experiment operations was not included. With this restriction, the study concluded that subsystem operations required only a low to moderate complexity of operations (compared with Apollo or the Shuttle Orbiter) and only a Spacelab high-fidelity mockup and a part-task trainer would be required. The mockup, however, would require a functional representation of the Spacelab subsystems. What actually happened later in the program was that a suitable mockup could not be obtained from ESA at what NASA considered a fair price (approximately $2.5 million), so the mockup was dropped and a simulator/trainer was built in the U.S. with assistance from the European contractors, although not to the degree of fidelity that JSC wanted. A part-task trainer was also developed and used effectively at JSC.

The final integration task of the study was originally intended to synthesize alternative total program approaches based on the four tasks and to consider such controversial issues as co-locating activities, sharing facilities and funding, and optimizing the use of hardware and personnel. The final presentation, however, was primarily a summary of the results of the subsidiary tasks. The primary alternative considered was the number of flights in the Spacelab traffic model.

Looking back on the impact of the Cost Reduction Alternatives Study, one would have to conclude that it was unsuccessful in changing the direction of the program. It resulted in no major change in program philosophy or system design. On the other hand, for the first time the flight operations organization within NASA took a substantial role in planning the Spacelab program. Prior to this time, JSC's participation had been focused on Spacelab/Shuttle interfaces and safety considerations related to carrying the Spacelab as a payload of the Orbiter. The study also awakened an understanding in the Spacelab team of the emerging role of dedicated microprocessors in handling experimental data.

Another critical aspect of Spacelab use was addressed by a KSC study contract, "Spacelab Operations at the Shuttle Launch Site." The first phase of this study was performed by TRW with McDonnell Douglas as a subcontractor from March to November 1975; J. J. Talone, Jr., was the KSC study manager. Hank Wong of the Headquarters Spacelab Program Office and Don Bailey of the KSC Spacelab Office provided guidance to the study team. The study objectives were to perform a detailed study of ground operations flows, perform an in-depth assessment of ground support equipment requirements, identify design criteria related to operational considerations, analyze design and operations concepts with regard to launch site safety constraints, and identify conflicts and recommend solutions.

In addition to developing detailed launch site functional flow diagrams, perhaps the most important result of this study was the development of design concepts for the assembly, test, and checkout stands to be built in KSC's Operations and Checkout Building. This task put the "meat on the bones" of the early concepts developed by the NASA team. Other results of the study provided recommendations for maintainability assessment, Spacelab/Orbiter integrated operations, alternative operational approaches for Spacelab launches from the Western Test Range, and additional needs for ground support equipment not previously identified.

ESA PAYLOAD ACTIVITIES

In the meantime, the European Space Agency made some important decisions about its own payload activities. First, it decided that ESA payload activities would be divided into two distinct phases: planning and realization. Planning activities would be the responsibility of the ESA Director for Future Programmes and Plans, Andre Lebeau. The second phase, which would start after the payload elements were chosen, would be the responsibility of the ESA Spacelab Programme Director, Bernard Deloffre. This would be the first step in increasing the number of duties assigned to ESA's Spacelab Director and differed from the action taken by NASA to establish a separate group for payload implementation.

At this time ESA also decided to establish the SPICE group (Spacelab Payload Integration and Coordination in Europe). Its responsibility would be to coordinate payload development and integration activities in Europe; prepare interface specifications; approve integration-related tests, compatibility, and safety aspects of European payloads; monitor schedules; maintain a technical competence for problem solving; and coordinate European Payload Specialist training programs. The group would be located at West Germany's DFVLR (its NASA equivalent) facility at Porz-Wahn near Bonn and report directly to Deloffre in Paris. Max Hauzeur was selected to head the SPICE group.

THE ROLE OF PAYLOAD SPECIALISTS

The subject of Payload Specialists is worthy of special note. From the beginning, NASA had envisioned three types of crew on Spacelab missions. Traditional astronauts with extensive test flight experience would, of course, perform the Shuttle command and pilot functions. Mission Specialists (career astronauts with scientific backgrounds) would perform the primary roles of operating the Spacelab and setting up systems to initiate experiment operations. In Spacelab, however, a new type of crew member would be included, the Payload Specialist. He or she would not be a career astronaut, but rather a career scientist with expertise in one or more of the experiments on a particular Spacelab mission. This Payload Specialist would be given minimal astronaut training in order to withstand the rigors of space flight and to operate Spacelab and Orbiter systems necessary for living and working in that environment. The primary role of the Payload Specialist would be to conduct the particular experiments in which he or she had special expertise.

The long hiatus of NASA manned space flight after the Apollo-Soyuz mission meant that a large cadre of pilot astronauts and Mission Specialists had to wait many years before they could hope for assignment to a Shuttle mission. Many people at JSC felt that these well-qualified and dedicated people should be given the opportunity to fly on the early Spacelab missions rather than relatively inexperienced and untrained (from an astronaut's standpoint) Payload Specialists. As it became obvious that the first Spacelab mission would be multidisciplinary and that all the scientific crew members would have to be cross-trained in a variety of disciplines, these arguments had merit.

Nevertheless, there was a point to be made that could be satisfied only by using Payload Specialists. The Shuttle had been advertised as opening a new era in space flight, where it would be possible for a scientist with minimum flight training to take an experiment into space. Furthermore, a commitment had been made to the Europeans that a European crew member would fly on the first Spacelab mission, and it was impossible to ignore the political importance of this commitment to the program and to future U.S.-European cooperation in manned space flight. And so it was decided that there would be two Payload Specialists on the first Spacelab mission—one from Europe and one from the U.S. Each side would select its own candidates, scientific training would be provided at the home laboratories of the Principal Investigators, and flight training would be conducted at JSC, MSFC, and KSC. During the course of astronaut selection and training for the first Spacelab mission, ESA decided to convert some of its Payload Specialists to "career astronauts."

KEY OPERATIONS AND DATA DECISIONS

In early 1976, NASA resolved two other key issues. First, in January NASA decided to locate the Payload Operations Control Center at JSC. Since earlier studies pointed out that the POCC would operate as an auxiliary to the Mission Control Center, this decision surprised no one, although there were strong arguments to decentralize flight control activities by placing the POCC at MSFC. A team at JSC immediately began to define the POCC and determine how it could be squeezed into the space available in the MCC building. It would have to provide not only general support equipment for monitoring all Spacelab missions, but also specific information and support equipment for each of the Principal Investigators on the ground during the mission. Interaction between the investigators and the onboard crew was paramount to the success of the Spacelab operational concept.

A second and related decision, was to assign responsibility for processing non-time-critical data from Spacelab payloads to Goddard Space Flight Center in Greenbelt, Maryland. GSFC would perform the same data processing function for Spacelab data as it already performed for many of NASA's automated spacecraft. Thus was born the Spacelab Data Processing Facility, an essential element of the Spacelab operational complex.

EARLY PAYLOAD DEFINITION

While these decisions were being made, other actions were taken to define the payload for the first Spacelab mission. ESA and NASA issued Announcements of Opportunity based on the guidelines approved by the two agency heads. Several hundred proposals were received from the European and U.S. scientific communities, and the selection of suitable experiments began. Within NASA, Bob Kennedy expanded his organization for planning the first mission payload by selecting Bobby Noblitt, formerly of the Spacelab Program Office, to be Program Manager for the Spacelab 1 payload. Technical support would come from MSFC, where O. C. Jean of the Spacelab Payload Project Office had designated Bob Pace as Mission Manager for missions 1 and 2 and Harry Craft as Assistant Mission Manager for Spacelab 1. By the time of the flight, Craft had become Mission Manager and would be key to the accomplishment of this major milestone.

Once the initial selection of experiments had been made by NASA and ESA, the hard work began. Weight was used as the principal bargaining chip for both sides, each receiving 50 percent of that allocated to the payload. The other resources were the subject of continuing (and sometimes difficult) negotiations right up until the time of flight. The Principal Investigators for the selected experiments were organized into an Investigators Working Group, which became the essential mechanism for negotiating changes in the allocation of resources such as weight, power, crew time, and data transfer. No organization was more important than this working group in creating and conducting a successful scientific mission. The interaction among these investigators with the onboard and backup crews, the Spacelab developers, the mission trainers and planners, and the operational support team was remarkable.

This cooperative response from the scientific community did not occur by accident. From the start, an aggressive activity within the program was to search for potential users and provide adequate information for their consideration. In its meeting on January 21, 1974, the Joint Spacelab Working Group decided a user's handbook should be developed, organized into two parts: a top-level User's Guide providing general descriptive information together with proposal and selection procedures; and a second-level Payload Accommodation Handbook providing detailed design information, performance specifications, experiment interfaces, payload environment, and operations information. A Sortie Lab User's Guide was already available in April 1973 before the program was approved. By September 1974 a joint ESRO/NASA Spacelab User's Guide had been prepared, and by November 1976 this had been condensed to a handy size and broadly distributed to potential users by ESA and NASA. A parallel effort by ESTEC and MSFC technical support teams resulted in the Spacelab Payload Accommodation Handbook. Some indication of the knowledge accumulated during this time can be gained from the fact that the October 1974 draft of the handbook was approximately ½-inch thick, the May 1975 draft was ¾-inch thick, and by May 1976 it had grown to 1½ inches. It appeared that the Spacelab and its users were ready to get together in a serious way.

Personal Reflections

We approached the space applications summer study sponsored by the National Academy of Engineering with considerably more optimism than the previous year's study by the National Academy of Sciences. First of all, engineers always seemed to look more favorably on manned space flight ventures than did scientists. Second, the applications investigators, particularly those in materials processing, were the "new boys on the block," i.e., they did not have the years of tradition of the space scientists and were hungry for new opportunities. Also, who could pick a more beautiful spot for a summer study than the mountains of Colorado? Nevertheless, it was going to prove very difficult to get ahead of our European partner in materials processing. West Germany, in particular, envisaged this as a potentially profitable area in space research and was moving aggressively toward the development of such experiments.

The cancellation of the Concept Verification Test program was a big disappointment in my Spacelab career. I thought it was a very worthwhile effort that should have continued indefinitely. One of my Headquarters directors, Bill Miller, was also convinced of the importance of this activity. In one case he waxed eloquently to me about the 1-megabit data bus that would soon be operational and he was anxious for the MSFC team to give me a demonstration. When the big day arrived, I stood there in front of the usual bewildering array of electronic racks and was told that the system was processing data at a rate of 1 megabit per second. As a former aerodynamicist used to seeing air flow visualized by smoke trails, tufts of twine, oil flow, or Schlieren photographs, I was dismayed to see absolutely nothing happening. It was much more interesting to hear the computer-generated voices—at least that was something I could sense!

On February 20, 1975 I gave a presentation on the Spacelab program to the Subcommittee on Space Science and Applications of the U.S. House of Representatives Committee on Science and Technology. Congressman Don Fuqua chaired the subcommittee and, as always, gave me a generous welcome and was very attentive to my presentation. What made this appearance particularly memorable was that Dr. Mary Helen Johnston, a metallurgical engineer from MSFC who had recently participated in one of the CVT mission simulations, made a short statement as a part of my presentation. She concluded by expressing the hope that someday she might have the opportunity to perform such experiments aboard Spacelab. Her dream very nearly came true in the Spacelab 3 mission when she served as backup Payload Specialist (fig. 43).

The end of the CVT program was not only a personal disappointment, but in my opinion it was a loss for the program offices that were to sponsor the Spacelab experiments. We were learning many techniques for reducing the costs to develop and conduct experiments in the Spacelab environment. I am convinced that many

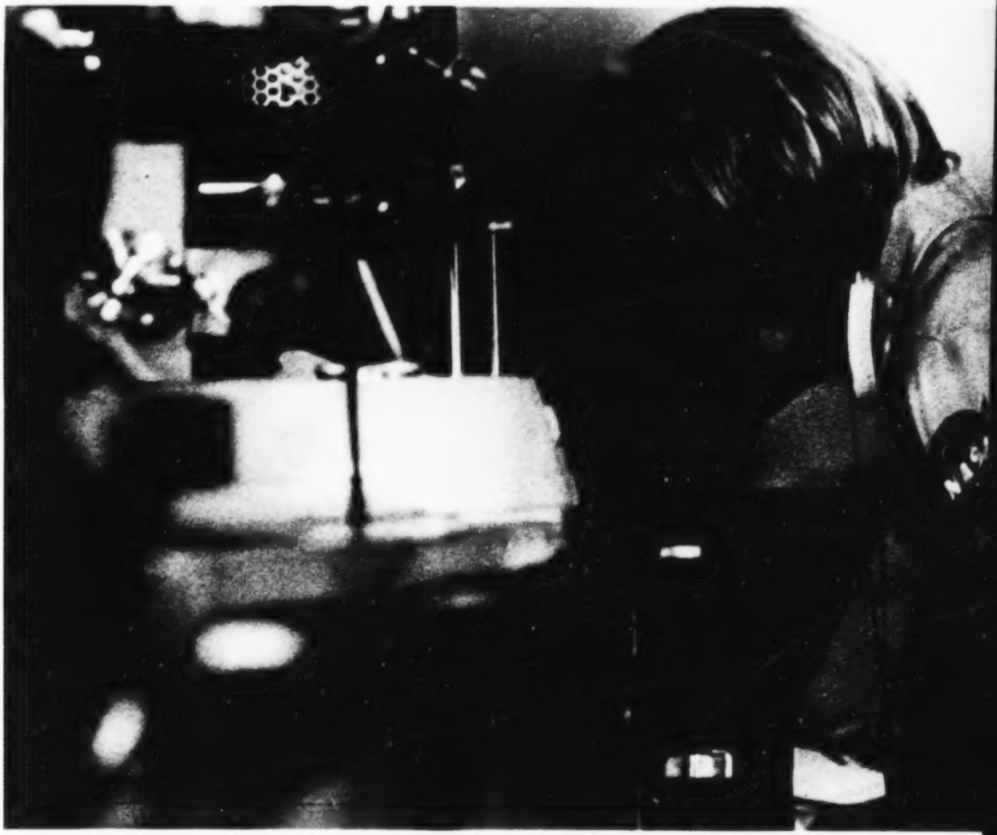


Figure 43. Material science specialist Dr. Mary Helen Johnston participates in a CVT simulation at Marshall Space Flight Center.

later criticisms about the high cost of Spacelab experimentation could have been avoided if we had continued to improve techniques in the low-cost CVT simulator. Nevertheless, the program was canceled, and my last view of the hardware was a glimpse of the discarded crew module structure sitting on a pile of forgotten space relics at the Huntsville Space Museum. Fortunately, other remnants of this effort had more useful afterlifes in the MSFC Spacelab crew training facility or in other space programs.

In some ways the ASSESS program was an even better simulation of future Spacelab missions because of the separation of the laboratory from its ground support team, the degree of risk involved, and the validity of the experimental data being gathered. It was, unfortunately, more expensive than the CVT simulations because of the cost of operating the aircraft. On one occasion we had the opportunity to share this showpiece of the Spacelab program with the European community. On September 27, 1974 the Ames Convair 990 airplane stopped at Schiphol Airport in Amsterdam on its return from another overseas research mission. ESRO set up a press conference at Schiphol at which Heinz Stoewer and I provided an overview of the Spacelab program and Don Mulholland from Ames described the airplane and the Airborne Science Program conducted on board. Jan de Waard of ESRO then described the upcoming joint ESRO/NASA mission. Everybody was then taken on a tour of the airplane to see how it was equipped for a typical scientific mission. The fact that de Waard was Dutch helped immeasureably in this brief exposure to the Spacelab program receiving excellent reviews in the local papers.

Preliminary discussions about the first Spacelab payload contained a number of subtleties. The principal issue, as noted, was whether to include a conglomeration of scientific objectives or to concentrate on a few scientific disciplines. Both approaches had strong proponents, but in the end the multidisciplinary payload was selected. I feel this decision was primarily political, one which provided something for everyone. It may also have been a marketing choice, with a successful mission demonstrating to all potential users how worthwhile Spacelab could be. The Europeans (in particular, West Germany) expressed a strong desire that a substantial portion of the experimental payload focus on space (materials) processing. Those on the U.S. side felt just as strongly (although they kept their feelings beneath the surface) that this should not happen and repeatedly told the Europeans that the first payload would emphasize science. It was suggested that onboard space processing would be too complex and would pose special problems in thermal and safety areas. In truth, we were concerned that the Europeans might achieve a major breakthrough in space processing that would reflect negatively on the cooperative effort. It was clearly recognized that materials processing was a very sensitive discipline, which perhaps would have to be treated in a proprietary manner by both sides. For its part, NASA quietly withdrew its objection to materials processing on Spacelab 1 and began definition of a NASA Spacelab 3 payload that would emphasize this discipline.

The primary issue for the second mission was entirely different. Here the question was whether Spacelab 2 would or could be a cooperative mission with Europe. Although we vacillated in open meetings with ESRO on this subject, eventually, through default rather than anything else, it became a dedicated U.S. payload. The only European experiments on board would be those selected from responses to NASA's Announcement of Opportunity. The primary question for ESRO (ESA) on Spacelab 2 was whether the Instrument Pointing System would be developed in time to meet the flight schedule.

The establishment of a Spacelab Payload Office under Bob Kennedy, inevitable though it may have been given the motivation of the sponsoring Office of Space Science, was a bit of a surprise to the Spacelab Program Office. (The first time I dialed Kennedy's office and heard the secretary answer, "Spacelab," I thought I must have dialed my own office.) In the Apollo and Skylab programs, once experiments had been selected for flight, the implementation responsibility was given to the program office within the Office of Manned Space Flight. Now a completely new (and difficult) relationship would have to be established between one office (Spacelab) under the Associate Administrator for Space Flight, responsible for funding and development of the carrier, and another office (Spacelab Payloads) under the Associate Administrator for Space Science, responsible for funding and development of the payload. Furthermore, planning the early missions would be further complicated because Spacelab flight verification would be top priority on the first two missions and the experimental payload would be of lesser priority. These organizational difficulties would present many problems over the next several years.

Prior to the selection of Kennedy, Gerry Sharp had been the key figure in early discussions of payload requirements and payload selection. Like me, Gerry was a teetotaler, and we shared many memorable trips to Europe, finding that France and West Germany were not famous just for their wine and beer, but also were wonderful areas to visit during the asparagus and strawberry seasons. Bob Lohman has a similar recollection of Gerry's affinity for ice cream sundaes, which they enjoyed in abundance in Holland and West Germany. Gerry did a superb job in providing the foundation of planning for the Spacelab payloads, and I regret the circumstances that caused him disfavor at NASA Headquarters and resulted in his transfer to KSC and eventual departure from the agency.

I cannot write of the Cost Reduction Alternatives Study without remembering one of my staff members and an important contributor to the study, Bob Lovelett. A former IBM employee, Bob was a free spirit who immensely enjoyed outdoor activities including riding his bicycle to work. He was also well ahead of the rest of us in recognizing the rapid development of computer technology and the probable mistake that had been made in Spacelab in placing too much emphasis on a centralized data system with inadequate growth capability. Unfortunately, commitment had been made to that system, and Bob was unsuccessful in getting us to scrap the system and start over. More tragic was his premature death while on a canoe trip with his wife, Mickey, in his beloved central Pennsylvania wilderness.

NASA viewed the establishment of the SPICE group as a power play by ESA to forestall West Germany's ambitions to become the integration center for Spacelab payloads in Europe. Nevertheless, by determining that the SPICE group would be located at its DFVLR facility and later by securing the assignment of the hands-on integration activities to ERNO, West Germany eventually got its way. Then by establishing a parallel organization to SPICE within DFVLR for the first German-dedicated Spacelab mission, D-1, it was relatively simple to eliminate the SPICE group after completion of the Spacelab 1 mission. Thus all capability for European integration of Spacelab payloads would end up in German hands.

Overall, one would have to conclude that despite many obstacles and differences of opinion on planning for the first Spacelab missions, a good job was accomplished. Though perhaps it would have been more satisfying to the NASA

Spacelab Program Office to have been responsible for development and operation of the experimental payload, we admire the performance of those in NASA and ESA who were responsible. I must admit that at times my group had its hands full just in assuring that Spacelab would be delivered in time and would provide an effective carrier for payloads. Whether the payload would have suffered or prospered had we been the office responsible is conjecture, at best. In any event, I commend the payload planners of ESA and NASA whose efforts completed the task that we Spacelab developers started.

6 Reviews, Reviews, Reviews 1975-1978

THE DESIGN BECOMES FIRM

As early as April 1975 it was reported that the first 2219 aluminum for the Spacelab had been cast by the Alcan Booth Company in England and module rings for the structural test module had been forged. Nevertheless, the program was not yet ready to go into full-scale production. In particular, the Preliminary and Critical Design Reviews had to be conducted.

The Preliminary Design Review (PDR) was intended to provide a technical review of the basic design of the complete Spacelab System to ensure compatibility with previously established technical requirements and the adequacy of the design approach. Successful completion of the PDR would result in the authorization of the prime contractor to design and manufacture the engineering model in accordance with the reviewed baseline. (The engineering model was to be a duplicate of the flight unit, but would not be qualified for flight.) In order to prepare the way for the PDR, ESA decided to conduct incremental reviews for each subsystem. Since the responsibility for the various subsystems resided with co-contractors of the prime contractor, ERNO, these reviews were dubbed Co-contractor Preliminary Design Reviews (CPDRs). They were initiated in the fall of 1975 and were to be completed by April 1976.

The prime/co-contractor setup within the Spacelab contract was a very interesting arrangement and quite different from the prime/subcontractor relationship with which the NASA team was familiar. In view of the multinational arrangement for contributions from the participating nations, the co-contractors on the Spacelab project (each of whom had a number of subcontractors) had considerable strength in the consortium. Of the 10 participating countries, only Austria and Switzerland were not on the list of co-contractors. Because of the low level of participation by these two countries, their principal share of the effort was represented by the subcontractors: OKG (Austria) provided part of the mechanical ground support equipment and the viewport, and CIR (Switzerland) provided part of the electrical ground support equipment.

No sooner had the CPDR schedule been established than it was apparent that it would be difficult to complete the reviews and revise the documentation in time for the overall system PDR targeted for May 1976. Thus it was decided to have a two-part review with PDR-A, a system overview, in June 1976 and PDR-B, the formal systems review, scheduled for the fall.

The winter of 1975-1976 was a busy time for the ESA team. In addition to the subsystem reviews, ESA Spacelab Programme Director Bernard Deloffre was driving his team hard to negotiate signed contracts with each member of the consortium, to reduce the backlog of engineering change proposals, to recover schedule slips, and to meet with numerous European and NASA groups necessary to review the many facets of the program. In order to improve NASA's visibility into the European contractor effort, Deloffre invited NASA program management to participate in his quarterly reviews at ERNO beginning in September 1975. These regular opportunities to meet firsthand with the contractor representatives and to share progress reports with ESA were invaluable aids to NASA in understanding ESA's and ERNO's problems. By the May 20-21, 1976 reviews, ERNO was able to show movies of the transport of the hard mockup core segment and end cone from Aeritalia in Turin, Italy via the Brenner Pass and shipment of two pallets from Hawker-Siddeley Dynamics in Stevenage, England via the North Sea. Together with the development integration fixture, these hardware articles gave a real sense of purpose to the newly completed Integration Hall at ERNO. This modern facility was to be the focal point for Spacelab integration activities for the next several years.

The good news during this time period was mixed with the bad. For example, at the March 4-5, 1976 Joint Spacelab Working Group meeting, ESA reported that, as a result of 2 weeks of strenuous effort, 110 engineering change proposals had been resolved with ERNO and only 90 were left open. Unfortunately, the cost of the changes recently approved was 15 million accounting units (approximately $15 million at that time). By March 19, Deloffre reported that his reserves on the program were down to only 5 MAU. (There had been 23 MAU in February.) Clearly the Spacelab budget was in trouble.

In any event, PDR-A was upon us. The major objectives, beginning with a presentation June 9 at ESTEC, would be to define system design status, assess interface definition, and define required tasks for PDR-B preparation. Joint ESA/NASA teams were to review technical documentation on system design integration and interfaces, avionics, and structural, mechanical, and environmental control systems. At my NASA Program Director's Review (conducted regularly throughout the program) on June 18, Luther Powell of the MSFC project team summarized activities in support of the PDR-A. NASA participants had been given strong guidance to write discrepancy notices only if the design did not comply with the requirements or was inadequate. They were not to propose improvements to workable designs, suggest tradeoff or optimization studies, or address problems that one could reasonably expect to be worked out in the normal course of design and development. The time to minimize changes was upon us, and we did not want NASA blamed for expensive program cost overruns.

In addition to specific concerns in subsystem areas, the NASA technical experts expressed concern that overall systems integration was lacking, the data package did not reflect the results of the CPDR's and the data package did not support 80 percent design release for the engineering model. Nevertheless, the team went through its planned reviews with ESA at ESTEC (June 24-25) and went on to Bremen for the final reviews between ESA and ERNO. By the time the senior NASA representatives (Bill Schneider, Deputy Associate Administrator for Space Flight, and myself) arrived on July 1-2, chaos reigned. Deloffre had submitted his resignation effective June 30, and ESA Director General Roy Gibson had just arrived to pick up the pieces. It was clear to everyone that PDR-A was a complete disaster! Documentation was inadequate, schedules were slipping, the budget could not be held, the contractor team was out of control, and team morale was at an all-time low. There were bad feelings on all sides—dissatisfaction with the contractor effort, condemnation of ESA's direction, and resentment of NASA's criticisms of the program. There were, however, encouraging signs. Roy Gibson would act as Programme Director until a replacement could be found and took a very positive approach to overcoming the existing problems. And Ants Kutzer, former ESTEC Project Manager for ESRO II (a scientific satellite project) and Project Manager for two German satellite projects, AZUR and Helios, was a very impressive addition to ERNO's management team as Deputy Project Manager. Klaus Berge, in turn, had been made Project Manager and Hans Hoffman had resumed full-time duty as ERNO Technical Managing Director, although with the latest problems he would remain actively involved in the program management.

One of Deloffre's most significant accomplishments during his tenure as Spacelab Programme Director was to formalize contractual documents with most members of the industrial consortium. Although ERNO had been given the go-ahead on Phase C/D in mid-1974, negotiations on a firm contract dragged until September 30, 1975, when the main contract between ESA and prime contractor VFW Fokker/ERNO was signed in the amount of approximately 600 million Deutschmarks (DM). Over the next 9 months, negotiations between ERNO and its co-contractors were concluded as follows:

Date	*Contractor*	*Subsystem*	*Type of Contract*	*Value (DM)*
Sept. 19, 1975	AEG-Telefunken	Electrical	Fixed price	46.8
Oct. 21, 1975	Hawker-Siddeley Dynamics	Pallets	Fixed price	35
Dec. 4, 1975	Fokker	Airlock	Cost reimbursement	18.8
Jan. 16, 1976	BTM	Electrical ground support equipment	Cost reimbursement	42
Jan. 19, 1976	Dornier	Environmental control life support	Cost reimbursement	72
Jan. 22, 1976	Aeritalia	Module, Thermal control	Fixed price	94
Mar. 5, 1976	KAMPSAX	Software	Cost reimbursement	7
June 21, 1976	SABCA	Igloo, bridges	Fixed price	7
July 9, 1976	SENER	Mechanical ground support equipment	Cost reimbursement	30
July 30, 1976	MATRA	Command and data management subsystem	Cost reimbursement	103.5

All contracts were concluded on the price basis of April 1, 1974. Of particular interest was the significant value committed on a fixed-price basis in this development effort.

With the ESA Director General in charge, things began to improve. By July 7, Gibson had signed a PDR implementation plan with Hans Hoffman of ERNO for a simple and straightforward approach to PDR-B. In addition, Gibson assigned a special team of senior ESA engineers to address the many change notices under review by ERNO and the co-contractors. Professor Massimo Trella, ESA Technical Inspector, assisted Gibson in addressing the Spacelab problems and co-chaired the September 15 Joint Spacelab Working Group meeting. By this time it was obvious that real progress was being made and the team spirit was greatly improved. Many open issues had been resolved, functional approaches accepted, interfaces between subsystems established, plans made, installation problems solved, and documentation for PDR-B initiated. NASA played a significant role in the improved situation and, as discussed later, had assigned a substantial team of technical specialists and management advisors to Europe. Finally, ESA selected Michel Bignier as Director of the Spacelab Programme effective November 1, 1976. Bignier had been the Director General of the French Centre Nationale d'Études Spatiales (CNES), the French equivalent of NASA.

Unless one has experienced a major review like the PDR on a manned space flight program, it is difficult to convey the mass of documentation, the detail of the technical information, and the complexity of the analyses that must be presented (fig. 44). Literally tons of reports must be distributed (on time) to the review teams in order to keep to a reasonable schedule. The documentation package arrived in the U.S. in early November 1976 and was reviewed by the usual large number of NASA technical experts. Simultaneously, the ESA teams were hard at work at ESTEC. Joint NASA/ESA review activities began in mid-November at ESTEC and continued at ERNO in late November culminating in ESA, ERNO, and NASA board meetings on December 4 and 8. NASA submitted more than 300 discrepancy notices and ESA almost 600 more for joint review. Of these, more than 600 discrepancy notices were approved by ESA and ERNO. Important special actions were initiated for software, structures, thermal control, the operational concept, the crew station review, and internal and external system interfaces.

By the end of the final board meeting at ERNO (fig. 45), all agreed that PDR-B represented a major turnaround in the program. The data package was a substantial improvement over previous efforts by the contractor team. The review emphasized solutions that would avoid hardware impacts. More importantly, the real problems had been brought out in the open and action plans were presented for solution. In his summary, ERNO's Hans Hoffman commented on the personal sacrifices that had been made in order to accomplish this review. He also noted that it had been necessary to violate social laws. This undoubtedly referred to excessive working hours by the contractor team in violation of local custom to hire additional workers rather than require overtime. In any case, all were hopeful that the program could now proceed in a more normal manner.

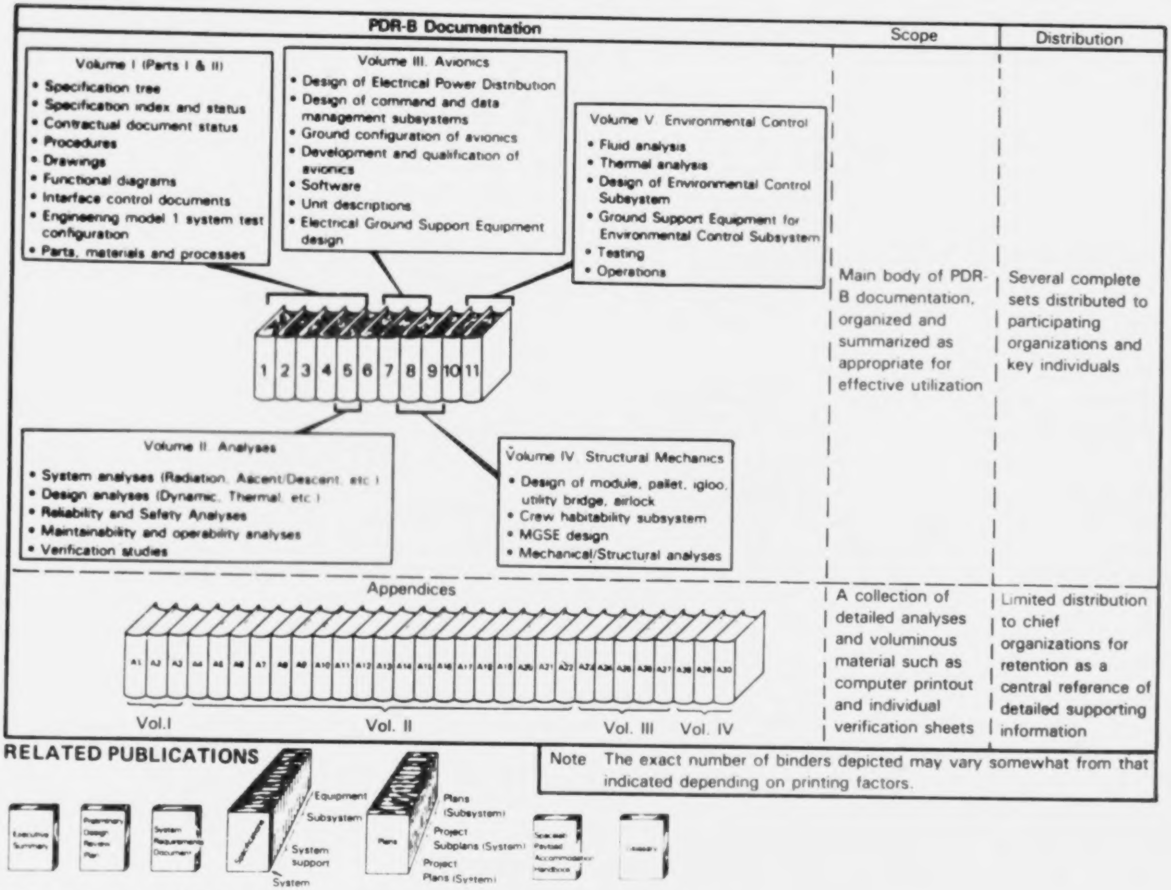

PDR-B Documentation
Scope
Distribution
Volume I (Parts I & II)
• Specification tree
• Specification index and status
• Contractual document status
• Procedures
• Drawings
• Functional diagrams
• Interface control documents
• Engineering model 1 system test configuration
• Parts, materials and processes
Volume III. Avionics
• Design of Electrical Power Distribution
• Design of command and data management subsystems
• Ground configuration of avionics
• Development and qualification of avionics
• Software
• Unit descriptions
• Electrical Ground Support Equipment design
Volume V. Environmental Control
• Fluid analysis
• Thermal analysis
• Design of Environmental Control Subsystem
• Ground Support Equipment for Environmental Control Subsystem
• Testing
• Operations
1
2
3
4
5
6
7
8
9
10
11
Volume II. Analyses
• System analyses (Radiation, Ascent/Descent, etc.)
• Design analyses (Dynamic, Thermal, etc.)
• Reliability and Safety Analyses
• Maintainability and operability analyses
• Verification studies
Volume IV. Structural Mechanics
• Design of module, pallet, igloo, utility bridge, airlock
• Crew habitability subsystem
• MGSE design
• Mechanical/Structural analyses
Main body of PDR-B documentation, organized and summarized as appropriate for effective utilization
Several complete sets distributed to participating organizations and key individuals
Appendices
A1 A2 A3 A4 A5 A6 A7 A8 A9 A10 A11 A12 A13 A14 A15 A16 A17 A18 A19 A20 A21 A22 A23 A24 A25 A26 A27 A28 A29 A30
Vol. I
Vol. II
Vol. III
Vol. IV
A collection of detailed analyses and voluminous material such as computer printout and individual verification sheets
Limited distribution to chief organizations for retention as a central reference of detailed supporting information
RELATED PUBLICATIONS
Note The exact number of binders depicted may vary somewhat from that indicated depending on printing factors.
Executive Summary
Preliminary Design Review Plan
System Requirements Document
Equipment
Subsystem
System support
System
Plans
Plans (Subsystem)
Project Subplans (System)
Project Plans (System)
Spacelab Payload Accommodation Handbook

Figure 44. Documentation for the Preliminary Design Review (PDR-B), November 1976.

Figure 45. The final ESA/ERNO board meeting at the second Preliminary Design Review (PDR-B) held at ERNO, December 4, 1976. The ERNO team is seated on the left, the ESA team on the right. At the end of the table are NASA observers, with technical advisors for all teams in the background.

Although 1976 might be looked at as the year of the PDR, other activities also took place. In April, ESA established a Software Audit Team to assess the software situation and make recommendations as appropriate. The team consisted of two French consultants from Management Scientifica (J. Ricard and H. Felix) and one NASA consultant (Steve Copps), and it met with all European companies involved in the development of Spacelab software (ERNO, KAMPSAX, BTM, MATRA, and CII). On May 12 the team presented its preliminary findings to the ESA Spacelab Programme and Project Managers. The final presentation to ESA, ERNO, and co-contractors was held on June 2, 1976.

Not surprisingly, the group concluded that Spacelab software was not in good shape. More importantly, it concluded that there did not seem to be a structure for improving the situation. The problem was not the complexity of the software required, but rather the large amount required and the diffuse relationship of the organizations responsible for the software (fig. 46). As shown in figure 47, at least five industrial contractors had software responsibility within the European Spacelab consortium.

The Software Audit Team recommended the following actions:

(1) Establish a software baseline.
(2) Determine the software needed from breadboard testing to flight unit testing.
(3) Establish a software control board.
(4) Generate software development plans.
(5) Revise the schedules; the existing hardware and software schedules were incompatible.
(6) Finalize software development and integration facility plans.
(7) Improve communications between contractor and co-contractors.

In summary, it was obvious that Spacelab management had not given software the proper emphasis. Although it is possible that this lag between software and hardware may characterize many development programs, major improvements would have to be made in the situation if the Spacelab integration and test program was to achieve a reasonable degree of success.

Another review of similar importance was the Spacelab Requirements Assessment and Reduction Review conducted jointly by ESA and NASA from March to June 1976. The Shuttle program had found this type of review valuable in taking stock of program needs and eliminating those items that had crept into the program but that, on close scrutiny, could be deleted and save considerable amounts of money. By this time, the Shuttle program had already had four such reviews. When Bill Schneider, Deputy Associate Administrator for Space Flight, heard of the serious funding problems encountered in Europe, he proposed that the Spacelab program take another hard look at its requirements. ESA had already proposed deleting the aft bulkhead airlock (which was to have been 1.5 meters long as opposed to the top airlock 1 meter long) and was thinking about deleting the peaking battery, analog recorder, and high-rate multiplexer. Jack Lee and Heinz Stoewer led NASA and ESA teams that identified and analyzed requirements which could be reduced or deferred with no significant reduction in payload accommodations capability in the operational period and with no cost transfer from one agency to the other. NASA held its Spacelab Requirements Assessment meeting on May 14 and a joint Level II review was held with ESA on June 8. Finally, a joint board co-chaired by Schneider and Deloffre met on June 14–15 to make initial decisions based on data developed by the teams. In addition to eliminating the aft scientific airlock and peaking battery, the most significant deletions agreed to were the laminar flow bench, a larger venting facility (for exhausting gases from experiments or obtaining a vacuum source from the space environment), the engineering model for ESA, and the European optical window (NASA would provide a Skylab window). The total savings were considerably less than ESA had hoped, though the exercise did provide a substantial increase in the unallocated reserve (approximately 7 million accounting units). Added to the 5 MAU of unallocated reserve reported in March, this would provide a cushion of 12 MAU in a cost-to-completion budget of 396 MAU—an improved but not very comfortable situation at this point in the program.

In the meantime, reviews related to Spacelab operations were beginning. On June 28, 1976 NASA distributed the data packages for the Preliminary Operations

Item	Co-Contractor/ Subcontractor	Country	Function	Status
IOBPS Input/output Box and Peripheral Simulator	MATRA/Dornier	France/ W. Germany	Simulation facility for development of command and data management subsystem	Now operating - some modifications pending
SCOC/ECOS Subsystem/Experiment Computer Operating Systems	MATRA/Dornier	France/ W. Germany	Operating systems for flight computers	Design is 70 percent complete. 30 percent of designed software is coded; some completed portions running on Mitra machine
Utilities	MATRA/Dornier	France/ W. Germany	Used for on-line and off-line software development	
ICS Interpretive Computer Simulation	MATRA/CII/ CAPSOGETI	France	Simulation of Mitra 125S computer for use on IBM 370	Now running at Matra and Dornier
MAS Macro Assembler System	MATRA/CII	France	Translates assembly language source code into Mitra 125S machine code. Used for software development and production	Now running at Matra and Dornier
LE Link Editor	MATRA/CII	France	Links assembler output into executable load. Used in combination with MAS for software development and production	Now running at Matra and Dornier
HAL/S 360 Compiler	Provided by ESA/NASA		Translates HAL/S source code into IBM 360/370 machine code	Available
HAL/S 125S Compiler	Provided by ESA Coded by STERIA	France	Translates HAL/S source code into CII Mitra 125S machine code to run on Mitra computer	About 70 percent complete
HAL LINK Linkage editor for HAL programs	Provided by ESA Coded by STERIA	France	Provides for HAL/S specific load functions not covered by LE	Nearly completed
DBGM Data Base Generation and Maintenance	ERNO	W. Germany	Generate, update and maintain a checkout data base which relates software logic to hardware. Extract on request from the checkout data base those data which are required for inflight and ground processing purposes	Detailed design underway
Flight SCOS/GCOS	ERNO	W. Germany	Integration of all operating system modules into checkout operating systems for flight computers	In definition
Ground GCOS	ERNO	W. Germany	Integration and check out of modules for ground operations	In definition
GOAL Compiler	Provided by ESA/NASA		Translates GOAL source code (checkout code) into interpretive code for use on the Automatic Test Equipment and command and data management subsystem computers	No development required
MMT Operating System	BTM/CII	Belgium France	Real-time operating system for CII computer in ground support equipment	Initial version delivered Further versions in development
GCOS Ground Computer Operating System	BTM	Belgium	Operating system for the ground computer (ATE) based on MMT	Detailed design under way
IOS Input/Output Simulator for Electrical Support Equipment	BTM	Belgium	Simulation facility for EGSE software development at BTM and ERNO	Design under way
Utilities	All		Used for software development at BTM	
Onboard and Ground Interpreters	KAMPSAX	Denmark	Executes checkout code by interpretation of interpretive code generated by the GOAL compiler. Interpretes keyboard inputs for operator/system communication	Preliminary design completed
C/O Checkout	KAMPSAX	Denmark	Programs to automatically check out the Spacelab in flight and on ground	Effort concentrates presently on test requirements
DR Data Reduction	KAMPSAX	Denmark	Software for data reduction during checkout	In design
RTSF Real-Time-Simulation Facility	ERNO	W. Germany	Real-time simulation for use during software integration at ERNO	Preliminary design underway
Load and Verify	ERNO	W. Germany	Facility to load software into command and data management subsystem via electrical groung support equipment	Development started

Figure 46. Software elements required for the basic Spacelab system, excluding the Instrument Pointing System.

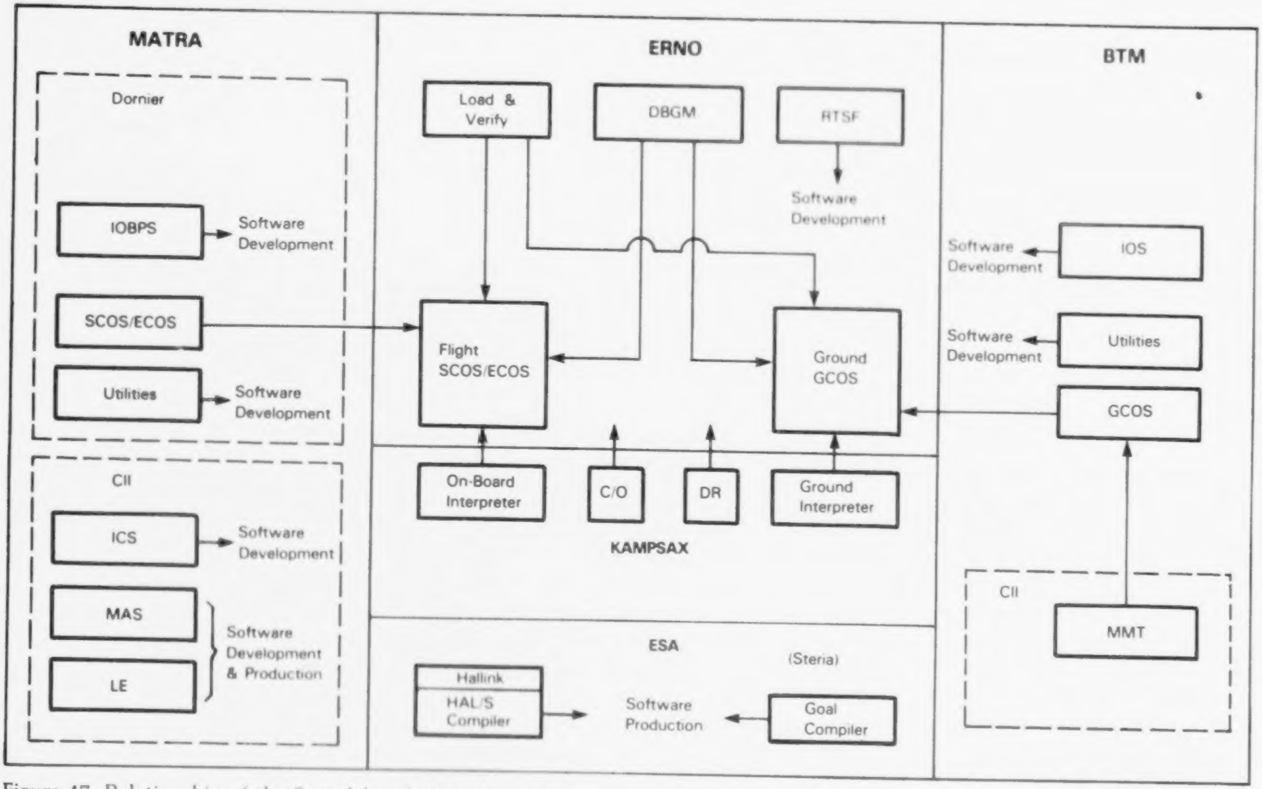

MATRA
Dornier
IOBPS
Software Development
SCOS/ECOS
Utilities
Software Development
CII
ICS
Software Development
MAS
LE
Software Development & Production
ERNO
Load & Verify
DBGM
RTSF
Software Development
Flight SCOS/ECOS
Ground GCOS
On-Board Interpreter
C/O
DR
Ground Interpreter
KAMPSAX
ESA
(Steria)
Hallink
HAL/S Compiler
Software Production
Goal Compiler
BTM
Software Development
IOS
Software Development
Utilities
GCOS
CII
MMT

Figure 47. Relationship of the Spacelab software elements.

Requirements Review for ground operations. The purpose of this review was to agree on ground operations requirements including integration at Level I, II, and III, logistics, training of ground processing personnel, ground support equipment, facilities, contamination control, and safety. Key to the accomplishment of these objectives was the assumption of a set of common flows for processing the eight Spacelab configurations by MSFC/KSC and ESA. NASA technical personnel (with some ESA support) conducted reviews of the documents in early July. Then three review teams assessed discrepancies and reported to a screening group co-chaired by Jack Dickinson of KSC and Ralph Hoodless of MSFC. By the time this group had finished discussing these issues, only 18 items had to be presented to the final board (chaired by Jack Lee) on July 30, and many of these were presented for information only. In summary, there appeared to be no major problem in Spacelab operations planning and, with the changes agreed, the requirements were considered to be baselined. "Baseline" is a term used in space programs to denote agreement with the documentation at the time, though it may be modified substantially by future change actions.

In the meantime, a subject troublesome from the start of the program bubbled to the surface again. The issue was whether or not to use the Orbiter general purpose computer to fully activate Spacelab subsystems. Because the Spacelab would be launched in a dormant state, initial activation of the subsystems for both the module and pallet-only configurations had to be accomplished before it could support payload operations. The original Spacelab baseline required manual switches located on the Orbiter aft flight deck to activate and control the Spacelab subsystem. As it became evident that this approach could require more than 400 switches, a significant amount of panel space in the aft flight deck, numerous wires across the interface, and substantial reconfiguration of the aft flight deck from flight to flight, the JSC flight operations people recommended an alternative. Step one was to use the Orbiter keyboard and display through the Shuttle general purpose computer and multiplexer-demultiplexer to activate and monitor Spacelab subsystems necessary to support its own data system. Once activated, a Spacelab keyboard and display would be used to activate the remaining Spacelab subsystems. It was only a short logical step for the JSC people to recommend using the Orbiter keyboard to perform the final activation as well as the initial step. Although it would double the amount of software required in the Shuttle general purpose computer for Spacelab activation, it would make it easier for the commander and pilot to monitor the Spacelab on orbit and would eliminate their need to be trained on the Spacelab keyboard and display system, which differed from the Orbiter system. There have been many second thoughts on this decision. It would rank near the top of the list of questionable decisions on Spacelab.

The use of the Orbiter general purpose computer was only one of the design considerations evaluated during this phase of the program. If 1976 had been the year of the Preliminary Design Review, 1977 was to be the year of preparing for the next major milestone: the Critical Design Review (CDR). ESA and ERNO scheduled a formidable series of Co-contractor Critical Design Reviews (CCDRs) to assure that each subsystem had been reviewed carefully and that supporting documentation would be forthcoming for the CDR. In June 1977, CCDRs were held for electrical and mechanical ground support equipment. Reviews were held in July for the data management subsystem and module structure. In September, reviews were held for crew habitability, system activation and monitoring, thermal control, and electrical power distribution systems. By November, reviews had been conducted on the life support subsystem, the igloo structure, and the airlock. As each of these reviews was completed, design releases were made and flight unit production was given the go-ahead. It was clear in all areas that substantial progress had been made since the completion of the PDR.

Thus the now-familiar review process was again readied for the CDR. The data packages arrived in the U.S. on January 16, 1978, and team reviews were held at MSFC with extensive participation from other centers and Headquarters. The NASA preboard met on February 7 and 8, and then the focus shifted to ESTEC for the joint team meetings starting on February 17. After a pause so that ERNO and its co-contractors could determine the impact of the proposed changes, the final phase of CDR began in Bremen on February 27, culminating in an ESA/ERNO/NASA board meeting on March 3 and 4.

Of more than 400 discrepancy notices generated by ESA and NASA and submitted to ERNO, only 17 were passed to the final board for resolution. One notable agreement was reached in the area of environmental control of the module, where ESA agreed to make changes to eliminate restrictions on pointing toward deep space. This so-called "cold-case fix" would not only maintain cabin temperatures but would allow reasonable selectivity for crew comfort. Although the CDR was very successful, certain problems were to be resolved later: software, pallet-only mode, igloo pressurization, integration and test requirements, and plans for NASA participation in closing out open items. It seemed that no review was complete unless it resulted in the need for more reviews.

Software was addressed simultaneously at the Software Requirements Review conducted from January 23 to March 10. At this in-depth review of the software requirements, ESA, NASA, and ERNO reached technical agreements for the first time. Four support teams developed and evaluated over 1500 discrepancy notices regarding subsystem computer, ground support, system, and support software. Two of the most important issues resolved were that NASA would henceforth participate in the ESA/ERNO Software Configuration Control Board and ESA would delete an onboard checkout interpreter.

Reviews of a different nature began during this time period as well. During the PDR-B on November 22–23, 1976, NASA astronauts Paul Weitz, Ed Gibson, Bill Lenoir, and Joe Kerwin conducted a walkthrough of the Spacelab module at ERNO (fig. 48). They spent several hours simulating various airlock operations and noting further improvements needed for the module. The first formal Crew Station Review was held at ERNO on April 25–29, 1977 and included NASA astronauts Bob Parker, Paul Weitz, and Ed Gibson. Working with NASA, ESA, and ERNO specialists in crew habitability, they reviewed the effectiveness of the Spacelab design through the use of mockups and engineering model hardware on site. Another review in February 1978 gave the astronauts the opportunity to review firsthand the scientific airlock hardware at Fokker and the improvements to the module at ERNO. Some of the problems encountered in these reviews were acoustic noise, inability to hear the intercom speaker, operations for fire suppression, airlock jettison mechanism, airlock hazards, and flatness of the experiment table (a lightweight framework inside the scientific airlock to hold experimental equipment and extend it out into space as needed). Although most of the astronauts' recommendations were taken very seriously and corrective actions implemented, their requests for correcting the intercom system were never accepted and this problem plagued the early Spacelab missions.

In the general area of Spacelab/Shuttle interfaces, actions continued to resolve open and emerging problems. The Interface Control Documents baselined in December 1975 had gone a long way toward stabilizing this very delicate situation, but by January 31, 1977 it was time for another major effort at Rockwell to update all the documents. Revisions were necessary not only to include data and decisions not originally available, but also to incorporate interface changes resulting from subsystem design changes as the Spacelab and Shuttle had matured. A total of 129 changes were presented at this meeting. Agreements were reached on 110, with 73 approved and 37 withdrawn or merged. The remainder were to be resolved pending further study on technical issues. Major mechanical interfaces at the keel and trunnion (side rail) attachments were resolved. Avionics hardware agreements were reached as well as ones concerning aft flight deck cooling. Significant open items remained in the software interface area between the Spacelab computers and the Orbiter general purpose computers. It was hoped that this would be the last major technical interface meeting and that subsequent issues could be resolved on an individual basis, since the logistics problems of getting together knowledgeable people from ESA, ERNO (and its co-contractors), Rockwell, MSFC, JSC, and NASA Headquarters were formidable.

One specific interface issue that received more than its share of attention was the location of the high-data-rate recorder. This key piece of equipment, which could record payload data at the astounding rate of 32 MBPS (million bits per second), would permit investigators to obtain data when the Spacelab was out of sight of either relay satellite. The Tracking and Data Relay Satellite System was planned to include two synchronous satellites positioned to provide almost continuous coverage for Shuttle orbits. In the case of the Spacelab module missions the recorder would be mounted in the module, and it was decided to train the crew in replacing the tape, but not to carry a spare recorder. In the pallet-only mode, ESA recommended placement of the recorder in the Orbiter aft flight deck to provide the same degree of reliabiity for astronaut accessibility as in the module configuration. NASA argued that the recorder should be placed on the pallet because the aft flight deck was becoming too crowded. NASA's decision appeared to be final, although by the time of the Spacelab 2 mission a recorder was placed on the aft flight deck. The experience of the first Spacelab mission was of particular importance in this regard and is discussed in chapter 11.

Two other reviews during this time should also be mentioned. In addition to responsibility for operations, NASA was responsible for development of some hard-

Figure 48. NASA astronauts Ed Gibson, Bill Lenoir, Paul Weitz, and Joe Kerwin conduct a walkthrough of the Spacelab module during the Preliminary Design Review (PDR-B), November 22-23, 1976.

ware items. The most important ones were the transfer tunnel (to provide crew access to the module from the Orbiter) and the Verification Flight Instrumentation (which would obtain data on Spacelab performance during its first two missions). The Preliminary Requirements Review for the tunnel was conducted from June 20 to July 12, 1977; a similar review for the VFI was conducted from August 1 to 19. In both cases, the goal was to secure end-item specifications for both systems so that design could be initiated by NASA and its new support contractor, the McDonnell Douglas Technical Services Company.

MANAGEMENT INFORMATION AND DECISIONS

During 1975, NASA responded to the first request for specific technical help in areas where ESA was having difficulty staffing its project team: flight operations, ground operations, and software. JSC was the first to respond by assigning Mel Brooks, who had extensive flight operations experience, to ESTEC. He was soon followed by Bill Oyler from KSC to help in ground operations planning and later by software expert Chris Hauff from MSFC. About the same time, Ron Thory from ESTEC took up his duties at JSC as ESA Spacelab Representative. Shortly thereafter, Dan Germany, who had been assigned to the MSFC Shuttle Project Office at JSC, became MSFC Spacelab Program Office Representative at JSC. These two individuals would be instrumental in resolving many problems in the Shuttle/Spacelab interface area.

Reference has already been made to the first two reviews of the Spacelab program by the Director General of ESA (ESRO) and the NASA Administrator in May 1974 and June 1975. These reviews, as called for in the Memorandum of Understanding, gave the agency heads the opportunity to evaluate the program's progress and to resolve issues that could not be settled by the Program Directors. For the Program Directors, it was an opportunity to bring in additional firepower to accomplish objectives we had been unable to achieve within the program structure. The next four "DG/A" meetings covered a wide range of Spacelab topics and provided a format in which to discuss other subjects of mutual interest.

The third annual meeting of the agency heads (Gibson and Fletcher) occurred on June 16, 1976 in Washington, D.C. Perhaps the most important issue at this meeting was that logistics requirements for the program had been almost totally neglected in the agreements and contracts to date. A special meeting was proposed for September to address the omitted issues. In other areas, the Program Directors were instructed to develop plans for configuration control of the Spacelab after delivery to the U.S., to develop a list and schedule of deliverables, to evaluate the need for long-lead procurement items in support of follow-on hardware which NASA might order, and to review their top problems regularly. ESA announced that it had given preliminary authorization to proceed with the development of an Instrument Pointing System. ESA also expressed its concern over NASA's recent release of a Request for Proposals to industry for Spacelab integration services without soliciting ESA's comments. Although ESA recognized NASA's responsibility for Spacelab operations, it had high hopes that a significant portion of this activity could be provided by its European industrial consortium. Thus Europe could obtain long-term financial benefits from its participation in the development of Spacelab.

The rollout of the Space Shuttle *Enterprise* on September 17, 1976 at Palmdale, California, provided an opportunity for the NASA Administrator to invite the ESA Director General to share in the occasion. On the following day, Gibson and Fletcher met at Ames Research Center to tackle Spacelab logistics issues. In the meantime, NASA and ESA logistics teams had attempted to scope the size of the problem. At the previous meeting of the agency heads, the rough estimate of effort required to develop a Spacelab logistics program was 490 man-years compared with the 153 man-years ESA planned to fund within the ERNO contract. The ESA and NASA teams developed a more rigorous assessment of the specific requirements for logistics analyses, documentation, and training, as well as direct (on-site) and indirect ESA manpower support during the first two Spacelab flights. The total estimated effort agreed to by this team was approximately 480 man-years.

When John Yardley reviewed these estimates, he disagreed with the degree to which off-the-shelf maintenance manuals would be available for Shuttle-common hardware and the time allocated for translation of available European commercial equipment documents into English. He also concluded that some 14.6 man-years of maintenance and supply effort could best be accomplished by NASA. The modified estimate of logistics effort required by ESA totaled 414 man-years—261 man-years more than its planned contractual effort. Both parties agreed that 153 man-years would be inadequate to perform the logistics effort needed for even the first two Spacelab flights, clearly an ESA requirement within the terms of the Spacelab Memorandum of Understanding. NASA argued that the MOU inferred that ESA should provide the total logistics effort needed in accordance with its commitment to develop a Spacelab system capable of repetitious use through the 1980s.

In view of all the problems facing Gibson at the time, his response was somewhat surprising. In short, he agreed that a 10-year operations approach to the logistics program was correct and would be initiated. He promised to formalize a response as to the funding of the program, and it was agreed that both sides would continue to review the requirements with a view to possible reductions. This was a major milestone in the decision-making process, and although there would be many obstacles ahead in the logistics area, a big hurdle had been overcome.

Other significant agreements reached at the Ames meeting were that NASA would fund development and production of demultiplexers to be used on the ground in consort with ESA-provided multiplexers on board Spacelab, NASA would reassess the need for video/analog recorders, and a spares policy would be developed. The multiplexer/demultiplexer issue had been particularly sticky. The multiplexer had been added to the data system to provide greatly enhanced capacity for transmission of simultaneous high bit-rate data streams from several experiments. From its inception, ESA had argued that NASA should provide the demultiplexer as part of its ground operations system whereas NASA had argued that the demultiplexer was part of the total system and should be provided, like electrical ground support equipment, by ESA. This was one case in which ESA won.

Soon after Bignier came on board in November 1976, he and Gibson recognized that Spacelab funding was out of hand, and proposed descoping the program. ESA was concerned that the program could be canceled if program costs exceeded 120 percent of the cost estimate made at the time the member nations signed the European Agreement. I should point out that this cost increase did not include inflation, and, according to the Arrangement, until the costs have reached 120 percent of the estimate as adjusted for inflation, no participating country may withdraw. Above that level, countries had the option to withdraw or continue with the program.

ESA had decided that another schedule slip was necessary and the cost of that slip plus the cost of the technical content of the program as presently defined would exceed the original cost estimate and require almost all the funds available up to the 120 percent ceiling. In explaining to its Spacelab Programme Board why the situation was so bleak, ESA listed the following reasons for the slow progress and high cost of the system design effort: shorter than usual Phase B study, slower than projected manpower buildup at the prime contractor, delayed definition of the operational concepts, additional user requirements, the parallelism of the Shuttle development which caused more changes than expected to the Orbiter/Spacelab interfaces; and delayed definition of the internal subsystem-to-system interfaces.

The budget envelope for the program in 1973 had been established at 308 million accounting units (MAU). When updated to the 1976 price level (and 1977 exchange rates) the adjusted envelope was 431.6 MAU. Unfortunately, the current cost-to-completion estimate was 494.2 MAU (approximately 115 percent). ESA's proposal to its board was that only by negotiating severe cuts in the deliverable hardware with NASA and exerting an iron will in regard to further modifications could the program be completed within the 120 percent ceiling.

The first list of items ESA proposed for descoping the program totaled 59.1 MAU in savings. The biggest savings would be achieved in five areas: cancellation of the Instrument Pointing System; cancellation of the pallet-only mode; reduction of the logistics, maintenance, and spares programs; deletion of the third set of ground support equipment intended to remain in Europe; and simplification of the command and data management subsystem. Other items proposed for descoping represented a clear transfer of responsibility to NASA, for example, development of the module atmosphere scrubber and qualification of the Skylab window.

On the NASA side, this exercise would provide a first test for the new Spacelab Deputy Director, Jim Harrington, who had started work as my deputy on August 9, 1976. Before joining NASA, he had been Vice President of Operations for the Periphonics Corporation and, earlier, Spacecraft Manager for Grumman on two of its Apollo lunar modules. At the time of the descoping proposal, I was hospitalized for back surgery, thus Harrington would have to oversee the review of the proposed cuts and prepare the way for top management decisions by NASA.

By January 13, 1977, it appeared to Harrington that the ESA proposals could save as much as $84 million in the ESA budget but could impose on NASA an additional funding requirement of $26-$33 million. The largest single cost to NASA would be to develop a replacement pointing system(s). These considerations were discussed by Fletcher and Gibson on January 14, and reasonable agreement was reached on the descoping items for ESA to go back to its Spacelab Programme Board for approval. By this time, NASA had agreed to develop not only the scrubber and qualify the Skylab window, but also to provide the ground support equipment for late access, provide the experiment computer operating system software, and accept the deletion of the core segment simulator. For its part, ESA had decided not to eliminate the pallet-only mode, but just to eliminate the igloo from the engineering model. ESA continued to hope that funding could be found elsewhere in Europe for the Instrument Pointing System. The proposal to simplify the data system had been relegated to the study phase rather than a specific cost-saving modification. With all these changes, the total savings to the ESA Spacelab budget appeared to be 49.1 MAU (including 18.0 MAU for the IPS deletion).

When Gibson returned to the Spacelab Programme Board on January 20-24 with the modified proposal as worked out with NASA, he received approval for all the proposed changes with one notable exception. The board refused to accept deletion of the Instrument Pointing System and decided instead to postpone decisions on this part of the program. It was obvious that the IPS effort, focused at MBB (Munich) and Dornier (Freidrichshafen), was an important political and financial contribution to southern Germany and one that could not be disposed of lightly.

The agency heads next met to discuss Spacelab 9 months later. On October 7, after touring several European government and industry facilities, the new NASA Administrator, Dr. Robert Frosch, met with Gibson in Paris. At this time, the target schedule for Spacelab flights 1 and 2 was December 1980 and April 1981, respectively. The Director General and Administrator noted, however, that slips in the Shuttle and the Tracking and Data Relay Satellite could require further slips in Spacelab planning. Their extensive discussion resulted in a modified approach to logistics by both ESA and NASA. Other agreements were reached on the Spacelab change control plan, the operational software, and the handling of proprietary data, which had been causing considerable difficulties within the program. Finally, ESA's concerns about NASA extending the capabilities of the pallets (already being modified for the orbital flight tests) rather than buying new ones were put to rest when Frosch agreed to "annually" abandon funding for such extensions unless unexpected events (i.e., ESA's failure to deliver) required such implementation.

On Spacelab-related matters, the agencies agreed to explore sharing instruments for future Spacelab missions, to study possible NASA participation in the two proposed European demonstration missions of Spacelab, to explore growth possibilities for the Spacelab system, and to consider some kind of an offset agreement to exchange goods and services by the two agencies. A more unusual agreement was to establish a joint "Imaginators" group who would develop a list of missions that would stretch the capability of the current Spacelab design. After concluding their discussions of Spacelab issues, Gibson and Frosch signed a new Memorandum of Understanding for the Space Telescope program and also discussed cooperation in such programs as the Out-of-Ecliptic (Solar-Polar) mission, Space Processing, Earth Observations, and the Tracking and Data Relay Satellite System.

Gibson's and Frosch's next review of Spacelab occurred in Washington on May 18, 1978. By this time the idea of an exchange agreement was heating up and the two exchanged letters agreeing to guidelines for value determination and mutual visibility. The thrust of the exchange agreement would be for ESA to provide additional Spacelab hardware to NASA, and NASA to provide an equivalent value of launch services to ESA. This approach had the advantage of reducing significantly the transfer of funding for NASA to procure additional flight hardware and for ESA to secure launch services for its planned Spacelab missions. There were to be several more discussions before this idea would finally be abandoned.

Gibson and Frosch also discussed the subject of Spacelab deliverables. As it became clear what ESA would deliver with the Spacelab flight unit, it was evident that shortages existed at the component level to support the first two flight missions. A resolution was accepted that provided a solution at least down to the level of cold plates, remote acquisition units, freon pumps, experiment interconnect stations, and experiment power distribution boxes. Without these additional components, it would have been impossible to process in parallel the experiments and Spacelab hardware for the first two Spacelab missions. An approach was presented for resolution of shortages in spare parts also. ESA agreed to provide up to 200 000 accounting units worth of additional European spare parts. Finally, the agency heads discussed briefly the status of the Shuttle schedule, the congressional situation with respect to the Solar-Polar mission, and remote sensing activities. At the time, the program situation would seem to have been fairly stable, with a congenial relationship established between the ESA Director General and the NASA Administrator.

Having traced the DG/A meetings in the period from 1976 to 1978, we now consider other significant management actions taken. In early July 1976, soon after Deloffre's departure, Gibson wrote to me expressing his thanks for Steve Copps' help with the Software Audit Team and questioning whether Copps might be available to assist ESA in implementing the audit team's recommendations. Gibson also indicated that ESA had needs in the areas of thermal control, data management, acoustic noise, and qualification and testing where NASA technical experts would be of considerable assistance. In Gibson's July 8 letter to Fletcher concerning the preparation for PDR-B, he reiterated the call for help. On July 26, he and Professor Trella met with Arnold Frutkin, NASA's long-time Assistant Administrator for International Affairs, myself, and others to explore the possibility further. Frutkin indicated NASA's willingness to provide technical specialists, but stated that it would have to be in the context of a support arrangement including management aspects of the program, and ESA would have to pay the incremental costs. Specifically, he indicated that NASA wanted management representatives at ESA Headquarters, ESTEC, and ERNO. NASA also stressed to Gibson the need for an ESA resident team at ERNO to maintain continuous oversight on the activities there, better exchange between ERNO and its co-contractors, better utilization by ERNO of its U.S. contractor consultants, and improvements in ESA project management.

On August 16, Fletcher wrote to Gibson stating that he had authorized the assignment of NASA technical and management-level personnel to ESA and emphasizing the following concerns: the need for a strong ESA resident team at ERNO, improved communications between prime and co-contractors, more effective use of the U.S. contractor consultants in Europe, and the addition of NASA advisors at the next level below the Project Manager.

By September 30, I advised Gibson that 12 NASA technical experts and 3 management advisors would be sent to Europe to assist ESA on the Spacelab program. The purpose of the technical experts was to assist the Europeans in discharging ESA's Spacelab responsibilities, and they would, therefore, be integrated into ESA's management team. They would receive their assignments through the ESA management chain and would have no responsibility for NASA requirements, NASA approval of ESA actions, or any other current responsibility of the NASA Spacelab Program Director or Program Manager. The eight technical specialists transferred on a permanent change of status were to be Copps, David R. Mobley (MSFC), Dick Bohlman (KSC), Robbie Brown (MSFC), Patty D. Feemster (MSFC), Alfred H. Fulmer (MSFC), Lamarr Russell (KSC), and Dean Hunter (KSC). Four additional specialists would be sent for brief periods: Leo Woodruff (MSFC), Dave Christian (MSFC), Jim Lewis (KSC), and Tom Purer (KSC).

For the management advisors, Bob Lindley, one of the senior directors from GSFC, would be assigned to ESA Headquarters; Luther Powell, Deputy Program Manager at MSFC, would be assigned to ESTEC; and Lowell Zoller, who had managed the early research and applications modules studies for MSFC, would be assigned to ERNO. Zoller would report to Powell, who in turn would report to

Lindley. Lindley was given the lofty title of Deputy Associate Administrator for Space Flight (European Operations) and was to report directly to Yardley.

By November 2, Gibson could finally reply to Fletcher's August 16 letter with a certain degree of optimism. Bignier had become Spacelab Programme Director (and was joined immediately by NASA's Lindley to sit at his side for the next year). An ESA resident team of 10 persons had been established at ERNO and co-contractor engineers also had been co-located at ERNO. The U.S. contractor consultants (McDonnell Douglas and TRW) were being used more on an in-line basis, and the NASA technical experts had been quickly integrated into the ESTEC team. Though Gibson did not say as much, certainly any problems in the present Spacelab management could not be attributed to ESA's failure to respond to NASA's advice nor to lack of NASA's participation and visibility in the program.

One more major change was to occur in ESA management before stability would return to the program. Bignier and Gibson concluded that a change was needed at the Project Manager level. Heinz Stoewer, who had been Project Manager since early in the program, was relieved of his duties in January 1977. Bignier took care to recognize Stoewer's contributions in building ESA's Spacelab team and guiding the program through the design phase. Feeling the need for a very tough Project Manager during the equipment construction phase, Bignier turned to Dr. Burkhard R. K. (Bob) Pfeiffer, former German Project Manager for the Symphonie Satellite and more recently head of the Space Transportation Systems Department at ESA Headquarters. Pfeiffer took over as Project Manager at ESTEC on February 1, 1977.

Management changes occurred on the NASA side, as well. The Headquarters Spacelab Office, recognizing the changing nature of the program, abolished the Experiment Accommodations Directorate headed by Rod Johnson and replaced it with a new Integration and Test Directorate headed by Al Ryan, formerly with the Shuttle Program Office. Johnson moved over to head the Advanced Studies Directorate in the Advanced Programs Office. Meanwhile, at MSFC, Bill Brooksbank, formerly the Concept Verification Test Program Manager, stepped in as Deputy Manager to fill Luther Powell's shoes during his year at ESTEC.

Other assignment changes were made to assure increased management attention and knowledge in the software phase of the program. At ESTEC, Franco Emiliani, who had already been made deputy to Project Manager Stoewer, was assigned to oversee the software program. In a similar move at ERNO, Ants Kutzer, also the Deputy Project Manager, was to devote a major portion of his time to assure that improvements were made in the software area. Nevertheless, not until 1978 could it be safely stated that the software problems were diminishing.

In a routine program review to Fletcher and Yardley in February 1976, I indicated my pessimism with respect to meeting planned Spacelab milestones. As a result of this report, Yardley decided to set up a team of senior NASA engineers to investigate these concerns. The group consisted of Walt Williams and Bill Schneider (Headquarters), Brooks Moore (MSFC), and Kenny Kleinknecht (JSC). Their first step was to attend the Quarterly Progress Review at ERNO, where the team was updated on the status of the program, and they requested that ESA and ERNO make arrangements for a series of plant visits. The week of March 14-20, the team, accompanied by Bob Lohman (Headquarters), Jack Lee (MSFC), and key ESA and ERNO officials, in an informative but hectic tour, visited six of ERNO's co- and subcontractors. The group visited Hawker-Siddeley Dynamics in Stevenage, England; BTM in Antwerp; MATRA and CII outside Paris; Aeritalia in Turin; and Dornier System in Friedrichshafen, West Germany. Without exception, the contractors were informative, helpful, and friendly hosts and impressed the team with their ability and determination to do the job. The team concluded that the co-contractors had a much better understanding of the situation within their plants than was reflected in the quarterly reviews at ERNO. The team was also very impressed with the quality of the hardware they were shown. Nevertheless, it was evident that the early phasedown of manpower levels and the hardware delivery schedules were unrealistic.

Administrators were not the only VIPs who found their way to Europe to review our progress. On October 12, 1976, Congressman Don Fuqua, a strong supporter of NASA manned programs, arrived in Bremen to be briefed by ESA and ERNO management and to get a look at the Integration Hall. Although this was before Bignier had come on board and the Spacelab team was still valiantly trying to recover from the PDR-A debacle, real progress had been made and it was possible to give Fuqua an optimistic report on readiness for PDR-B.

During the week of May 30, 1977, John Yardley, the NASA Associate Administrator for Space Flight, visited Hawker-Siddeley Dynamics, ERNO, and Aeritalia to review firsthand the status of the program and progress on hardware fabrication. At HSD the first development pallet had been instrumented for static testing, the second unit had been assembled, and the third unit was in assembly. As Yardley's background was aircraft structures, he was like a kid in a candy store. He was also delighted to find that the high-temperature adhesive (used to secure the thin skins to the honeycomb panels of the pallet) was in its final testing and that HSD was prepared to deliver four pallet segments to be used in the Orbiter flight tests. Three of these were engineering model segments and one a flight unit segment. The pallets could be used for carrying experiments in the otherwise empty (except for development flight instrumentation) cargo bay of the Orbiter.

Yardley's next stop at ERNO provided him with the customary status reviews, tour of the facilities, and some extrapolation by ERNO of its future plans. The only area of substantial controversy related to proprietary rights, where both sides were accusing the other of withholding information. Aside from that, Yardley was impressed with ERNO's progress on the program. During his final Spacelab stop at Aeritalia, he spent another marathon session discussing structures and thermal control systems and touring the manufacturing and test areas. With two development units of the module in structural test and the qualification unit in manufacturing, there was considerable hardware to see. In addition, testing was under way on both passive and active thermal control components. Again, Yardley was impressed with the engineering, manufacturing, and testing progress.

In regard to the problems with proprietary data, the fundamental issue is that such data are handled differently in Europe than in the U.S. In Europe, the government had no legal rights to data which the contractor considers to be proprietary, even though the data are developed under a government contract. In the U.S. NASA has rights to all information and data developed under its contracts. It soon became evident during the major program reviews that neither ERNO nor ESA had data to the level of detail that NASA was accustomed to seeing. Furthermore, if data were available, they were marked "proprietary" by the responsible contractor and could not be distributed to NASA contractors for the conduct of NASA operational duties. It was apparent to NASA that ESA was not inclined to pressure its contractors to obtain free use of such data by NASA. There were two obvious reasons for this reluctance: ESA and its contractors were concerned that NASA and its contractors could use the detailed drawings to reproduce Spacelab hardware that NASA otherwise would have to purchase in Europe, and ESA and its contractors were hoping there would be a significant role for European industry in providing support to NASA during the operational phase in areas where Europe had technical expertise. It was obvious that unless some solution was found to this dilemma, NASA would be hampered in trying to operate the Spacelab system.

I was assigned to negotiate an agreement stating the "Principles and Procedures for Transfer and Handling of Technical Data Between NASA and ESA Under the Spacelab MOU" with Dr. W. Brado of the staff of the ESA Director of Administration. I secured the assistance of Garland McCoy of the NASA General Counsel's staff and took off for Paris to work out an agreement with Brado on September 29 and 30, 1977. The crux of the agreement was to differentiate between proprietary and nonproprietary data and to set up a protective means of handling only that which was truly proprietary, i.e., design features or manufacturing or inspection processes which, in the view of the providing party, give to an industrial firm a distinct competitive edge over other firms. Such data would be stamped with a limited rights notice stating that they could only be used and disclosed to implement obligations under the Spacelab MOU. Each side agreed to establish a central control and screening point to ensure that only data meeting the definition were marked and to maintain a record of the location and use of such data.

Frosch and Gibson approved this approach at their meeting on October 7, 1977, and Bignier and I signed the document that day. On November 17, we signed a second document that provided Level I guidelines for the classification of data. Each agency was then able to establish its own administrative procedures to assure proper safeguarding of proprietary data.

On May 28, 1976, NASA (MSFC) had issued a Request for Proposals for a Spacelab integration contract. This RFP, issued with very little warning to ESA, was to secure a contractor that would provide NASA with support in two vital areas: development of those items of Spacelab hardware which were NASA's responsibility, and providing analytical and hands-on support in the integration and checkout of Spacelab hardware during the operational lifetime of the system. It was a very attractive contract, estimated to have a value of some $100 million over the next 15 years.

The RFP contained the assumption that design authority for the Spacelab would be transferred to NASA with the flight unit. ESA immediately objected to this assumption. ESA also felt that NASA planned to undertake tasks with this contract which were ESA's responsibility according to the Spacelab MOU. NASA defended its actions by pointing out that the integration contractor would support NASA in conducting the tasks for which NASA was responsible. In any case ESA was offended, and so it was agreed that ESA would review the RFP for areas of conflict, and NASA would give due consideration to the value of European contractor support within the planned contract.

A number of aerospace contractors expressed interest in the integration contracts, and two very strong teams submitted proposals; one consisted of Boeing, TRW, and Teledyne-Brown; the other of McDonnell Douglas, IBM, and Northrop. In the meantime, ESA had decided not to increase its funding for operations support to Spacelab in view of the critical situation with respect to its development costs. Instead, ESA kept the pressure on NASA to ensure industrial participation for Europe by direct contracts with the NASA integration contractor. NASA refused to be forced into directing such direct contracts, but recognized that there could be a logical supporting role for European contractors. The level of such activity would be decided by the integration contractor selected.

On March 9, 1977, NASA announced that the McDonnell Douglas team had been selected for the integration effort. The cost-plus-award-fee contract was estimated at $43.5 million for the period from March 1977 through December 1983. The winning company, called the McDonnell Douglas Technical Services Company, was a McDonnell Douglas subsidiary established to avoid overhead costs of the parent company and would be headquartered in Huntsville, Alabama. However, the work would be done primarily in two parts at MSFC and KSC. The company's unwieldy acronym (MDTSCO) was soon expressed throughout the program as "Mah-desk-o." IBM was to provide ground and flight software within the contract and Northrop would provide general engineering support. Thus was born a very important segment of the overall Spacelab team, which would be instrumental in bringing the system to operational readiness.

Even with award of the contract, ESA did not give up its efforts to secure a larger piece of the pie for Europe. The MDTSCO contract envisaged a very minimal support contract to ERNO. At the next Joint Spacelab Working Group meeting, Bignier stated that ESA would check whether or not a conflict of interest existed between the MDTSCO contract and the existing Spacelab development effort funded by ESA. He also stated that ESA would explore whether there were other tasks than those proposed by MDTSCO that European industry could reasonably do on a competitive basis due to its specific development experience. By the time of the next JSLWG meeting in May, Bignier admitted that it would be very difficult for ERNO to play a significant role as a subcontractor to MDTSCO because of the extremely low manpower costs MDTSCO had offered to NASA. Nevertheless, by January 1978, 79 man-months of ERNO support effort had been negotiated with MDTSCO, and MDTSCO was considering an additional 735 man-months of support. It appeared that there would be, at least to some degree, a marriage of convenience.

Also of importance to the program during this time period was initiation of activities leading to the procurement of Spacelab hardware by NASA. Article VIII of the Memorandum of Understanding was titled: "NASA Procurement of SLs" (Remember the dispute as to whether to name it "Sortie Lab" or "Spacelab.") This article made three basic points: (1) NASA agreed to procure from ESRO (ESA) whatever additional items (beyond the first flight unit) it might require, *provided that they are available to the agreed specifications and schedules and at reasonable prices to be agreed;* (2) NASA would refrain from separate and independent development of any SL *substantially duplicating the design and capabilities of the first SL;* and (3) NASA would give ESRO advance notice of any prospective requirements for *substantially modified or entirely new SLs* so as to provide ESRO (ESA) with an opportunity to make proposals which might meet such requirements. The phrases italicized above are not italicized in the original text, but were to become key points for subsequent debate.

At the start of the program, discussions of how many Spacelab units NASA would need fluctuated wildly, depending on the size of the Shuttle traffic model being used, the percentage of Shuttle flights that would be dedicated to Spacelab missions, the assumption made on the number of Spacelab elements, and the processing time. As the Shuttle traffic model and the percentage of flights dedicated to Spacelab were reduced, the requirement for Spacelab hardware diminished rapidly. Then the negotiation to include a second set of subsystems with the igloo essentially doubled the capability of one set of Spacelab hardware. Finally, Fletcher made a commitment to ESA that NASA would procure one complete unit, to be identical to the flight unit that ESA would deliver. The Europeans did not hide their dismay that what they thought would be an order for several flight units had dwindled to a single one.

Nevertheless, to get the ball rolling on procurement following the June 1976 DG/A meeting, NASA furnished ESA with a list of data needed after the PDR to serve as a basis for NASA's Request For Proposals for follow-on procurement. ESA then furnished NASA an elaboration of follow-on production items and details of possible long-lead item procurement. On August 25-26, the first joint meeting was held in Paris to discuss and resolve issues concerning NASA's procurement of a high-fidelity mockup. It was clear at this meeting that some fundamental differences between U.S. and European procurement practices would require waivers from normal U.S. procurement regulations. As pointed out earlier, the plan to purchase the hi-fi mockup in Europe was subsequently abandoned for other than procurement problems.

On November 18-19, the Spacelab representatives from NASA and ESA met at ESTEC to discuss schedules, composition, and cost alternatives for follow-on procurement. Two alternative delivery schedules were discussed: a NASA schedule based on hardware requirements to support the planned mission model and an ESA schedule designed to reduce costs by eliminating production gaps. It was obvious that NASA wanted to delay procurement until additional hardware was required to meet its mission needs. ESA, on the other hand, was anxious to keep its production team fully occupied, rather than to have a hiatus. ESA reminded NASA on a regular basis that the MOU required NASA to place an order 2 years before the delivery of the first Spacelab. Of course the validity of that delivery schedule was always a debatable issue.

By May 1977, the issue of production gaps from ESA was balanced against NASA's arguments that it had not received a suitable deliverable items list or contract end-item specifications for the flight unit. In other words, NASA could not expect to write a definitive contract for the second unit if it did not know the content and quality of the first unit which ESA was to deliver. Both sides agreed to work harder toward obtaining the necessary documentation and waivers to permit a go-ahead.

Personal Reflections

Learning to work with the Europeans and what we sometimes called the European mentality was an interesting experience. In fact, there was a mentality for each nationality involved, and I'm sure the U.S. or NASA mentality was just as strange to our European partners as theirs was to us.

Europeans, we discovered, took their holidays very seriously—nothing ever stood in the way of a planned vacation! And with 10 European countries involved, we soon learned that there was seldom a week when there wasn't some national holiday, feast day, religious observance, or election planned. Failing all else for disruptions, there was sure to be a major football (soccer) tournament or strike under way.

As if there weren't enough excuses to stop action on the program, right in the midst of the Co-contractor Preliminary Design Reviews, Deloffre, Stoewer, and Hoffman decided it would be a good idea to have a Spacelab ski week in Nauders, Austria. The stated purpose of this venture was to foster a European Spacelab spirit and to strengthen friendly bonds between those working on the program. ERNO's Spacelab newsletter of the time describes the fun had by all under the unlikely title of "Tyroler Schlittenfahrt." Pictures of the occasion suggest that all the participants had a wonderful time and the worries of the Spacelab program were cheerfully ignored for that week. The adventure was never repeated on such a scale, although occasional groups did arrange to sneak off when schedules would permit. (The Americans were always at a distinct disadvantage when skiing against their Alpine-bred counterparts!)

Interruptions of another sort were to befall me. In February 1976 I discovered that I had coronary artery disease. By March an angiogram had shown the severity of the situation, and in April I underwent double bypass surgery. Fortunately, I recovered quickly, returned to work in 5 weeks, and a week later was en route to Europe for a Quarterly Progress Review at ERNO, a Joint Spacelab Working Group meeting in Paris, and a visit to AEG-Telefunken in Hamburg. In a cartoon given to me at my retirement, my MSFC friends jokingly indicated that the surgeon was still sewing me up as I headed for the plane. Bill Schneider had filled my shoes during my absence and was ably assisted by my program office staff led by Bob Lohman, Rod Johnson, and John Kelly. There was no slowdown in the program; nevertheless, it was good for me to be back at work and feeling great.

The relationship between the prime and co-contractors within Europe's Spacelab consortium was a particularly difficult arrangement (fig. 49). As pointed out earlier, these program assignments had sometimes been made to fulfill a requirement for equitable distribution of funds (back to their national source) and other times were made for purely political reasons. The co-contractors felt they were equal to ERNO, the prime contractor, and in terms of their national representation on the Spacelab Programme Board (one country, one vote), they were. Thus, if the pro-

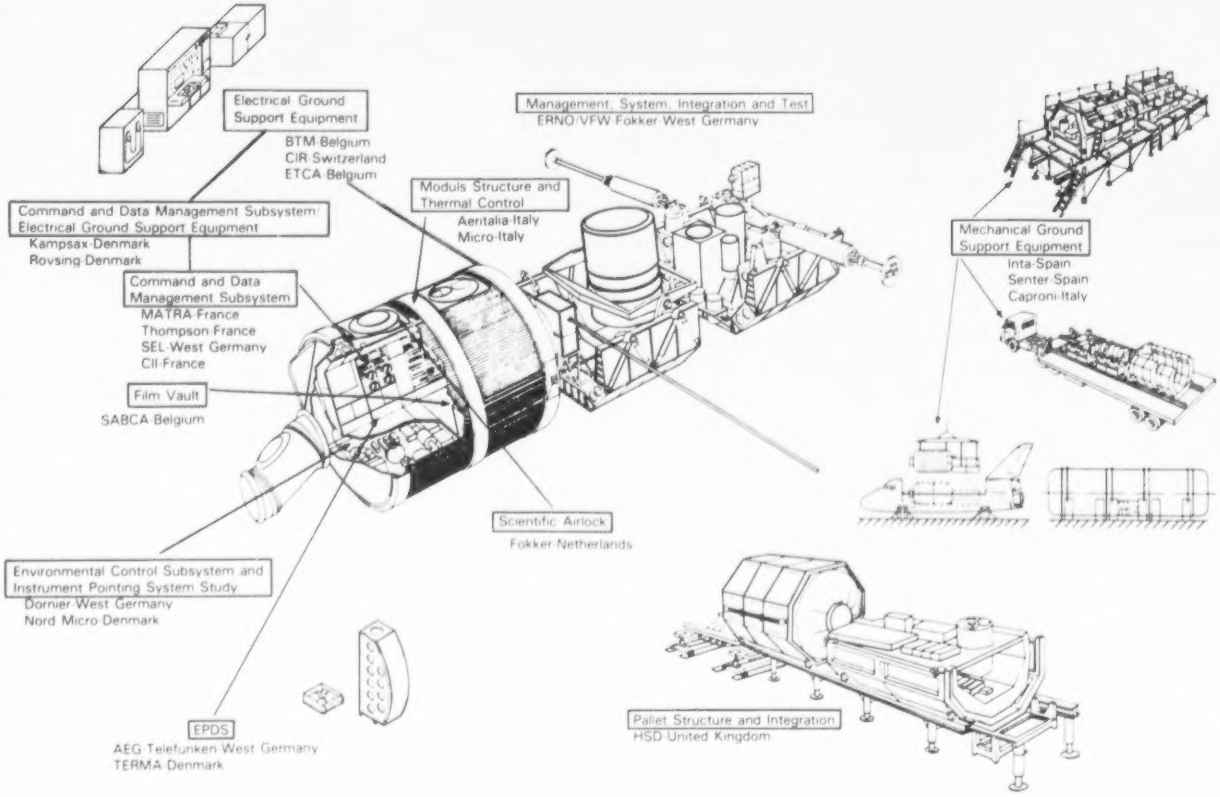

Electrical Ground Support Equipment
BTM-Belgium
CIR-Switzerland
ETCA-Belgium
Management, System, Integration and Test
ERNO/VFW-Fokker-West Germany
Moduls Structure and Thermal Control
Aeritalia-Italy
Micro-Italy
Command and Data Management Subsystem/Electrical Ground Support Equipment
Kampsax-Denmark
Rovsing-Denmark
Command and Data Management Subsystem
MATRA-France
Thompson-France
SEL-West Germany
CII-France
Film Vault
SABCA-Belgium
Mechanical Ground Support Equipment
Inta-Spain
Senter-Spain
Caproni-Italy
Scientific Airlock
Fokker-Netherlands
Environmental Control Subsystem and Instrument Pointing System Study
Dornier-West Germany
Nord Micro-Denmark
EPDS
AEG-Telefunken-West Germany
TERMA-Denmark
Pallet Structure and Integration
HSD United Kingdom

Figure 49. European prime contractor (ERNO) and subcontractor responsibilities for Spacelab elements. The senior subcontractor in each area was designated as a co-contractor to ERNO.

gram was not to their liking, they could protest through their national representatives. ERNO was therefore placed in a very difficult position as the team leader and had to tread lightly in directing its team members. Until top ESA and industry management recognized this situation and brought pressures to bear, the industrial management of the consortium was very weak, at best.

NASA took every opportunity possible for ESA representatives to participate in the NASA hearings before Congress. On January 27, 1976, Deloffre testified before the Senate Committee on Aeronautical and Space Sciences, and on January 29, Gibson presented testimony before the House Subcommittee on Space Science and Applications. There was no question but that Europe's significant participation in the Space Transportation System with its development of Spacelab was a persuasive argument for maintaining the schedule and support for the Shuttle.

Support of another kind was afforded by detailing Dr. Edward Gibson to ERNO from March 1976 to March 1977. An experienced astronaut and Skylab crew member, Ed was given a 1-year fellowship and was invaluable in bringing firsthand scientific and astronautic expertise to ERNO's Spacelab activities.

An entirely different program activity under way at the time was the Spacelab display at KSC. As part of the 1976 United States bicentennial celebration, an exhibition on science and technology sponsored by various government agencies and leading industrial firms was held at KSC. Within NASA, the Spacelab program was provided the opportunity to present a public Spacelab display. In the cooperative spirit that has characterized the Spacelab program since its inception, NASA and ESA provided one of the exhibit's best displays. The major components consisted of ESA's full-scale mockup of the Spacelab module and MSFC's full-scale mockups of the Spacelab pallet and the tunnel (fig. 50). An estimated 40 000 people viewed the display the first day it was opened. Fortunately, after the exhibit ended, ESA consented to an extended loan of its module mockup to MSFC where it became an essential element for training Payload and Mission Specialists for the Spacelab 1 mission.

Looking back on Deloffre's departure from the program, it is interesting to speculate on the reasons that precipitated his resignation. It is possible that Director General Gibson had lost confidence in his ability to control the program. Deloffre and I had negotiated a "package deal" that cost ESA a considerable amount of money and, coupled with other program changes, had almost depleted the program reserves. Further changes in process could drive the cost-to-completion out of sight. Furthermore, Deloffre felt isolated by Stoewer from the realities of the program, their relationship had become increasingly combative, and neither one was successful in getting control of the contractor team.

Following Deloffre's departure and the abortive PDR-A in Bremen, I left for a vacation in Southern Germany, Austria, and Switzerland. Perhaps it was not the best time for me to leave, but Gibson needed time to reorganize his ESA and ERNO team, and I was due for some rest. My wife, Barbara, and I had a superb vacation despite one of the hottest summers in European history. On our nation's 200th birthday, we were blissfully cruising up the Rhine River on an excursion boat. We also discovered the nonalcoholic beverages of Germany: Johannesbeer, traubensaft, orangensaft, and spezi—an enjoyable mixture of Coke and fruit juice. And in our repeated (and unsuccessful) effort to secure ice we soon recognized the standard response: "Ja, ist kalt!" All work was not forgotten, however, as my persistent staff repeatedly tracked me down in such unlikely places as Herzogenaurach or Rottach-Egern to inform me of progress being made on the program, and I also found time to make a quick visit to Dornier System.

Traveling in Europe, however, was simple compared with living there. The NASA men transferred to Europe soon found out one truism: if you have a good washing machine, your wife will be happy. (In most cases the wives were unable to obtain work permits and spent most of their time as homemakers.) Some of the early transfers attempted to make do with the European models, but soon found them to be too small and too slow. After one of the families discovered that the Sears Company made a washer that was compatible with European electrical systems, everybody had to get one. For most of the NASA employees, the European assignment was a financial as well as cultural shock. Fortunately, the financial loss was offset to a degree by the opportunity for European travel, recreation, and educational opportunities. Every family had its tales to tell of the difficulties of living in Europe, but probably the most unusual occurrence was the premature delivery of a baby to the Lamarr Russell family while touring in England. The baby was delivered by the royal family's obstetrician and probably would not have survived without the very special care received there. When Bill Hamon, our liaison man at ESTEC, was asked who would pay the hospital bill, he replied in typical fashion: "Don't worry about it, we'll take care of that later. Just do it!"

The hospitality extended to NASA visitors to Europe was always outstanding, but none exceeded that given by Hans Hoffman of ERNO and his wife, Elke. A one-time Fulbright scholar in Kansas and, with Bernd Kosegarten one of the so-called "2-meter twins" (because of their height) of ERNO, Hoffmann enjoyed to the fullest his friendship with his American visitors. Hans and Elke often opened their Bremen home to visitors and provided many memorable occasions and opportunities to become better acquainted with our program partners. One special meal, never to be forgotten, was a traditional north German meal of kohl and pinckel—a cabbage secured just after the first frost and a ground pork dish. Washed down with beer and schnapps, it made for a very friendly and noisy dinner.

Hans delighted in taking us to quaint restaurants in and around Bremen, but his favorite was the Schwarzwald Stuben (Black Forest Restaurant). After a filling meal, the inevitable climax was a round or two of Hexengeist, a witch's brew served flaming with appropriate incantations by the head waiter. When asked what this drink tasted like, one unnamed guest replied, "asphalt!"

The most unusual character for the Spacelab visitors in Bremen was undoubtedly Heinz Lichtsinn, the proprieter of a small hotel not far from the main train station. Some of the U.S. contractor consultants had discovered this delightful inn, and it soon became a favorite place for many of the NASA team as well. Heinz delighted

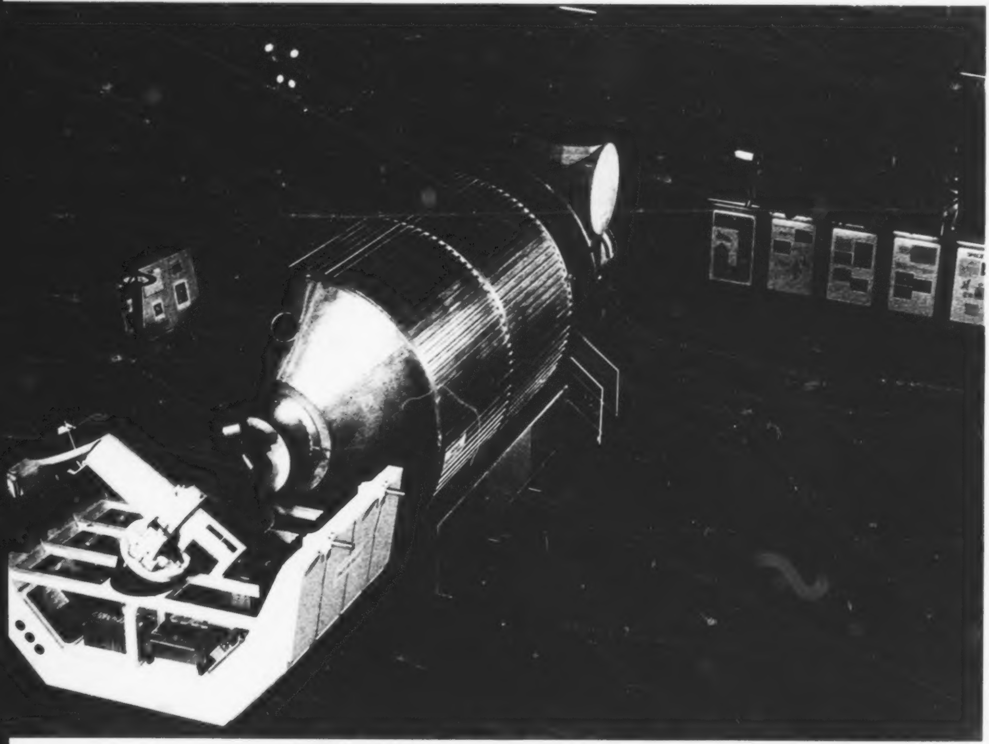


Figure 50. A view of the full-scale mockup of the Spacelab, part of the 1976 American Bicentennial exhibit at Kennedy Space Center.

in entertaining everyone from behind the bar with his booming voice, sometimes broken English, and always friendly laughter. Breakfast was served by Heinz and his wife, which provided everyone with a great start to the day. The hotel Lichtsinn only had one drawback: the room reservation system, also operated from behind the bar, was subject to hourly changes, and Heinz could teach the airlines a thing or two about overbooking. Nevertheless, this enjoyable man, who actually seemed to like Americans, became a friend to many of us, and we were all delighted when he appeared at Cocoa Beach, Florida for the launch of the first Spacelab mission.

Detailing Bob Lindley to ESA Headquarters to provide administrative support required several personnel shifts within NASA. Bob, an old friend and associate of John Yardley, had been in charge of satellite programs at Goddard. In order to secure his release from GSFC, Yardley had to agree to assign Bill Schneider, then his deputy, to fill Lindley's position at Goddard. Glynn Lunney, in turn, was borrowed from JSC to fill Schneider's position as Yardley's deputy at Headquarters.

Bob was a very effective consultant to Bignier for the next 8 months. He was particularly effective in bringing to the attention of VFW-Fokker Chairman Gerrit C. Klapwijk the need to strengthen the management relationships among the members of the Spacelab industrial consortium. Unfortunately, a family tragedy required Bob to return to the U.S. in July 1977. Yardley then picked Kenny Kleinknecht as Lindley's replacement. Kleinknecht, a long-time NASA employee who had been involved in all the NASA manned programs, immediately moved to Paris where he continued as the NASA management advisor to Bignier for the next 2 years, until Yardley needed him at KSC to resolve the installation problems with the thermal tiles on the first Shuttle Orbiter (fig. 51).

Conducting joint NASA/ESA meetings with Lindley or Kleinknecht seated on the opposite side of the table was a very interesting, though sometimes frustrating, experience for those of us on the NASA team. These two seasoned veterans of NASA and U.S. industry negotiations could be very difficult adversaries when they took a strong stand in support of an ESA position on a technical or programmatic issue. They were both individualists who enjoyed the give-and-take of technical arguments and were not the least bit reticent to challenge NASA proposals. Of course they also provided strong augmentation of the ESA staff in leading the government and industry team in Europe.

Their apartments in Paris gave insight into their different natures. Lindley's residence was a modest, Bohemian-style apartment on a back street not far from the Palais-Royal. From its windows, one could sense the charm and conviviality of a typical Parisian neighborhood. Kleinknecht's apartment, located on the Avenue du President Kennedy high above the Seine, was a real showplace. From the balcony, one could see the whole of the Eiffel Tower, completely dominating the foreground. Both homes were welcome gathering spots for NASA contingents visiting Paris.

After the formation of ESA, members of the "head office," as the Europeans refer to their headquarters, looked for a new office location in Paris. The ESRO and ELDO offices had been located in a commercial office building north of the Arche de Triomphe in the area called Neuilly-sur-Seine. Eventually it was decided to purchase and remodel an old factory building for the new ESA Headquarters building. Located near the École Militaire and UNESCO Headquarters, the new facility was also conveniently close to the Cambronne station on the elevated part of the Paris Metro and had an enclosed garage. Covered by gray tiles, the building gave the impression of a clinic, but was a very modern facility with outstanding offices and conference rooms. The conference rooms with cubicles for translation in four languages (English, French, German, and Italian) were particularly impressive. The council room, where the largest ESA meetings were held, had a central table that was 80 square meters in area (approximately 20 by 40 feet).

Sometimes, unusual visits related to the program required more than the normal care and planning. NASA Administrator Fletcher's June 1975 visit to Paris for the annual Spacelab review with ESRO Director General Gibson included several

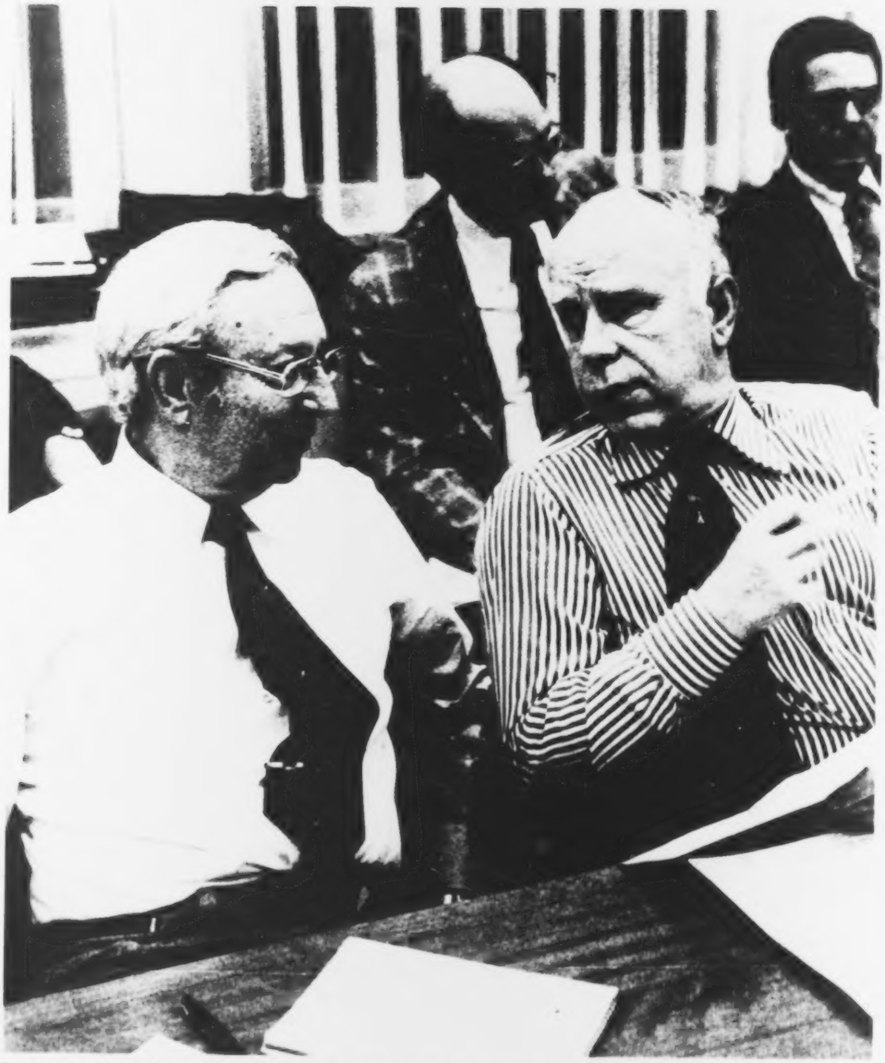


Figure 51. NASA technical advisor Kenny Kleinknecht with ESA Programme Director Michel Bignier at the Critical Design Review at ERNO, March 4, 1978.

days at the Paris Air Show, followed by a trip to Bremen for a more detailed report on Spacelab progress and a tour of the facilities and Spacelab mockup. While in Bremen, Fletcher was entertained at a dinner by Professor Gerhard Eggers, the Chairman of ERNO, then at a luncheon hosted by Chairman Klapwijk of the parent company, VFW-Fokker, and, finally, at another dinner with the Lord Mayor of Bremen in the historic Kaiser's room of the City Hall. A particular treat for Fletcher during this visit was a tour of the A. G. Weser Shipyard where supertankers were under construction. Fletcher also journeyed to Munich to meet with MBB President Ludwig Boelkow (the middle "B" in MBB) and later with Drs. Hans-Hilger Haunschild and Wolfgang Finke of the West German science ministry for general discussions of German space activities.

I recall some exciting moments during Fletcher's visit. First, while taking off from Paris in a Caravelle airplane, we lost one engine and had to return quickly to the airport. During the wait for a replacement aircraft, we enjoyed a short meeting with Jacques Cousteau who happened to be passing through at the same time. Then when we arrived in Munich, we were whisked off the loading ramp before entering the terminal and taken by MBB to the fanciest hotel rooms we had ever seen. We could envision our government per diem allowance sinking into oblivion under the cost of those rooms. Fortunately, it was not Oktoberfest and we were given a reduced rate. It was easy to see that MBB pulled considerable weight not only with the airport, but with the Bavarian government, as well. When we arrived at MBB, it also became obvious that our host hoped we would use our NASA influence on the West German government to secure more space contracts for MBB. Fortunately, Dr. Finke of the West German ministry arrived to relieve the pressure on us.

During Congressman Fuqua's visit to Germany, he was the surprised recipient of a special promotion, courtesy of Lufthansa Airlines. When the flight crew learned they had an American congressman on board, they awarded him with a large pin that said "Senator," which they had on board for special VIPs. Needless to say, Congressman Fuqua made the most of his temporary elevation to the upper chamber.

When the NASA technical team traveled to Europe, there were unique circumstances. First, the group had no designated chairman. Bill Schneider and Walt Williams each felt he had the mantle, Schneider because of his position as deputy to John Yardley, and Williams because of his seniority in NASA and position as NASA Chief Engineer. Actually, Kenny Kleinknecht could have claimed the title with similar credentials to either of the other two. In any case, the sparring for position between Williams and Schneider was nothing more than an irritant on the trip and the final report was authored by Williams. They were, in fact, good friends and both brought considerable expertise to the examination of the program.

Another unusual circumstance about this trip related to publicity about conflict of interest of government employees. A number of government employees recently were cited for accepting favors from government contractors such as goose hunting expeditions, airplane trips, and other such entertainment. The NASA General Counsel had issued a very stern directive that NASA employees could accept no such favors. The team decided that Bob Lohman would negotiate with each host on the trip to ensure that the government team members paid their own way. At the first stop, in England, Lohman explained the situation to the HSD hosts after an outstanding dinner. HSD insisted that it was unthinkable for NASA team members to pay for their dinners, but Bob persisted. Eventually, after much objection, HSD quoted a figure for the dinner which was considerably more than the government would reimburse the NASA men for their total expenses for the day. By contrast to this situation was the visit to Aeritalia in Italy. Again, an outstanding dinner. Again the insistence that NASA employees must pay. Again the protests from the Italians. Finally, when he realized the NASA team was adamant, the Aeritalian host said: "Well, okay, but tonight it was a very special price: $1 each!"

During Frosch's first visit to Europe, we were all concerned about the impression to be made by our new Administrator. NASA personnel familiar with his get-acquainted visits to the NASA field centers had found him to be a difficult personality to read. His visits to ESTEC and ERNO did not improve our feelings. Although relaxed and cordial, he seemed uninterested in the briefings, the program hardware, and the facilities. We could not tell if he was pleased or displeased. Nonetheless, he kept to a very full schedule, accompanied by Arnold Frutkin, Walt Williams, and Pat Murphy. In Holland, he visited both ESTEC and the Dutch space facility (NIVR) at Delft and signed the Infrared Astronomy Satellite (IRAS) agreement with officials of the Netherlands and the accompanying scientific support agreement with a representative of the United Kingdom. At Bremen he was briefed by ERNO Spacelab officials and visited both Spacelab and Ariane (2nd stage) facilities there. He also met with VFW-Fokker Chairman Klapwijk and the Spacelab Board of Directors. In Bonn he met with West German science ministry officials and signed the Jupiter Orbiter Probe agreement. Finally, he met with Gibson in Paris to review the Spacelab program and to sign the Space Telescope agreement. During the Spacelab discussions, we finally got to see our new Administrator in his best light. The inability to process in parallel module and pallet-only mission hardware had frustrated me from the beginning of the program. Frosch recognized my concerns, argued eloquently for the necessary hardware, and assured that action was taken toward resolution of this pesky problem. I was delighted!

During Frosch's visit, I took some good friends including the Kleinknechts and Walt Williams to one of my favorite restaurants: Au Vert Bocage. Imagine our surprise when the Gibsons came in with their party including the Froschs, Frutkins, Mellors, and Bigniers. Of the thousands of restaurants in Paris, what was the chance of our picking the same one? Then to compound the probabilities, Frutkin spotted an acquaintance at another table, who turned out to be Dave Beckler, Staff Director and my immediate boss on the White House staff 15 years previous. He was now the Technical Director of the Organization for Economic Cooperation and Development in Paris.

As I recall the exhausting number and variety of reviews within the Spacelab program, I should not neglect those of a more routine nature that contributed to the management process and its relationship to other elements of the overall program. I convened my Headquarters staff for a weekly meeting in our modest project control room, which we shared with Chet Lee's Operations office. Although I am sure my staff members sometimes felt these weekly torture sessions were a waste of time, for me it was a good discipline to assure that each member of the team was fully apprised of activities within the program and had the opportunity to make his or her contributions. Equally important, the regular review of assigned action items assured that open issues would not be forgotten.

In a similar fashion, I was required to attend weekly staff meeting of the Associate Administrator for Space Flight, where I regularly reported on how Spacelab activities related to the other activities under the province of our Program Associate Administrator. On a monthly basis, a general management review was held by the NASA Administrator, where all the NASA program offices made regular reports of progress and problems. Periodically, I would be required to make one of the "featured" presentations and would be subject to criticism from the Administrator's staff and the other program offices.

Another regular review process was provided by the Manned Space Flight Management Council, an organization continued from the Apollo days. The Management Council was chaired by the Associate Administrator for Space Flight and consisted of his senior staff members plus the director and senior staff from the manned space flight centers (KSC, JSC, and MSFC). This group usually met monthly, rotating among the three centers and Headquarters. Normally the center directors avoided raising controversial issues at these meetings, preferring to fight their turf battles on a different playing field where they had better control of the action, but occasionally controversy would arise in the course of a particular program presentation. Times aboard NASA's Gulfstream aircraft, which transported us to and from these meetings, also provided the opportunity for solution of problems between program directors or with the Associate Administrator. Perhaps, because of the relaxed atmosphere and conviviality we shared on these flights, problems which seemed insurmountable during a formal meeting could be resolved at 30 000 feet altitude.

Approximately quarterly, I also held a Spacelab Program Director's Review, or what some of our field center cohorts preferred to call a "dog and pony show." The reviews were held at one of the three manned spaceflight centers or at Headquarters and fulfilled a number of objectives. First, they gave me and my staff a chance to sit face-to-face with our technical support teams and to be brought up to date on the problems and progress. Second, they gave us the opportunity to see firsthand the progress with hardware and the facilities located at each field center. Finally, they assured us that the three field centers were working together in coordinating their respective assignments and in preparing the way for the early Spacelab missions. When travel restrictions forced us to reduce the frequency of these reviews and to substitute teleconferences, I felt the program suffered.

7 At Last–Hardware!
1976-1979

EARLY MILESTONES

In earlier chapters, mention was made of the initiation of hardware manufacturing as early as 1975 and pressure tests of the module in 1977. These were typical of the fabrication and testing under way in every subsystem area during this period. Nevertheless, it was not until the completion of the major design reviews that production of hardware could begin in earnest. Although it is beyond the scope of this book to detail the problems encountered in the development of each subsystem, it should be of interest to highlight some of the key problems in each area and the ways in which the particular co-contractors provided solutions.

MECHANICAL GROUND SUPPORT EQUIPMENT (MGSE)

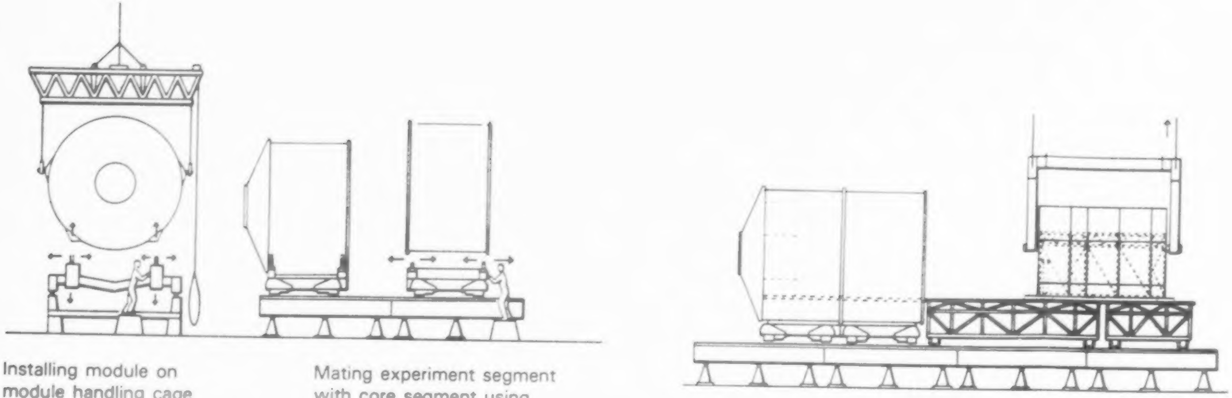
It may seem strange to begin this discussion with MGSE, since it is usually a part of the development story that receives little publicity and oftentimes insufficient attention by management. It is, in fact, an area that faces the proverbial chicken/egg syndrome. How does one design equipment to handle the flight hardware before the Spacelab itself is designed? On the other hand, how can one have the handling equipment ready when the Spacelab hardware arrives if one does not design and fabricate the handling equipment first?

This was the quandary facing the Spanish government agency INTA when it began the definition phase of the MGSE. The MGSE was subsequently turned over to SENER, a Spanish industrial contractor, for final definition and development. Prior to June 1976, SENER had been a principal subcontractor to INTA, so this transition was handled very smoothly. It is a tribute to this team that somehow answers were found to the scheduling problems and MGSE was never a serious bottleneck in the program.

Five basic challenges faced the MGSE development team. First, it was to develop handling equipment for all major elements of the Spacelab, including handling cages, hoisting devices, assembly stands and fixtures, and installation aids. Second, it was to provide access equipment such as workstands, scaffolding, access kits, and floor covers. Third, it was to provide a capability for transportation and storage that would include transportation platforms, soft covers, desiccants, and transportation tie downs. Fourth, it was to provide certain checkout items to determine weight and balance, to conduct leak checks, and to verify environmental control life support components. Finally, it was to provide for servicing of the gaseous nitrogen system and the fluid loop of the active thermal control system and environmental control life support system. An illustration of the mechanical ground support equipment for assembly of the Spacelab module is shown in figure 52.

At the time of PDR-B, the MGSE consisted of 76 different items, 57 of which were the responsibility of SENER, and the others the responsibility of subsystem contractors: Dornier System for 9 environmental control system items, Aeritalia for 6 items for thermal control system support, and Fokker for 2 items related to the airlock. Not only would the MGSE be used within Europe for the initial integration and test activities, it would also have to be suitable for support of NASA operations during a 10-year operational period. Given the modular nature of the Spacelab concept, this was a difficult challenge, indeed. The two massive cylindrical segments of the module, each approximately 10 feet in length and 14 feet in diameter, and their matching end cones would have to be positioned precisely for mating and so that the O-ring seals (used to provide pressure integrity) could be installed and verified. These segments were too large in their normal orientation for transportation and would have to be rotated 90° to be carried tuna-can style. The eight double racks and four single racks for mounting avionics equipment and experiments within the module had to be supported and transported singly or in groups and at times attached to the floor of the module though outside the module itself. Similar though less difficult challenges were posed by the modular pallets and the igloo.

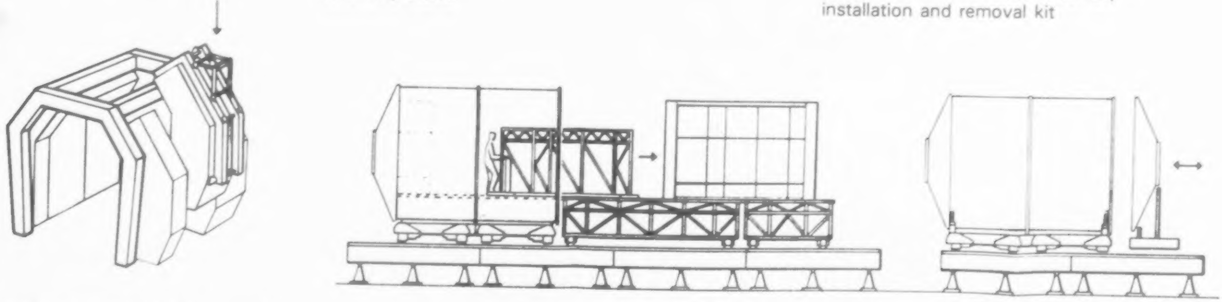
When the SENER equipment started arriving in Bremen for installation in the ERNO Integration Hall, everyone was impressed with the massiveness of the stands and handling cages. The principal SENER equipment was easily distinguishable by its bright blue paint. It soon became evident that, though massive, this equipment was made to work and to last. The system for installing the floor and racks into the module, not unlike the way airlines install baggage containers in the holds of modern-day aircraft, was particularly impressive. Designs for several important items including the module handling cage, the pallet segment support, and the rack and floor braces kit were rejected early because of excessive weight and capacity. This problem was solved by SENER through separation of the transportation functions of these items from their integration functions. Although many people contributed to these achievements, the leadership of Felix Cabana of INTA, and Jose Dorado of SENER deserves special recognition.



Installing module on module handling cage supported by assembly stand

Mating experiment segment with core segment using module handling cage on assembly stand

Installing rack and floor assembly using the rack and floor assembly installation and removal kit



Installing racks on the support braces kit

Rack and floor assembly braces kit being used to install rack and floor assembly

Installing aft end cone using aft end cone stand

Figure 52. Concept of the mechanical ground support equipment for assembly of the Spacelab module.

ELECTRICAL GROUND SUPPORT EQUIPMENT (EGSE)

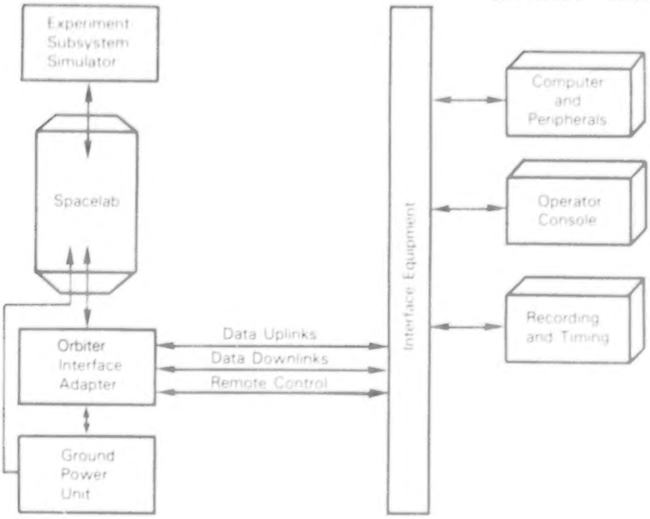
The Bell Telephone Manufacturing (BTM) team at Antwerp, Belgium, faced the same dilemma in defining the EGSE that the MGSE team encounterd. How could one develop an electrical checkout system for the Spacelab when the onboard avionics system and the interfaces between the Spacelab and the Orbiter were in such an indecisive state?

The principal purpose of the EGSE was to provide for test and ground checkout of the Spacelab during Level II and Level III integration as the Spacelab and its payload were united. Both automatic and manual modes were to be provided. The central item of equipment, diagrammed in figure 53, was the Automatic Test Equipment (ATE), consisting of a three-station operators' console with keyboards and CRT displays, a CII MITRA 125 computer with peripherals, recording and timing equipment, components for making measurements and generating stimuli, and interface equipment. Remember that the selection of the French CII computer had been based, in part, on the availability of an identical flight and ground-based unit. In addition to the Automatic Test Equipment, BTM was initially charged with development of a ground power unit to duplicate the Orbiter power supply, an Orbiter interface adapter to simulate the Orbiter power and signal interface, an experiment segment/pallet simulator to simulate power loads for the Spacelab electrical power system and signals for the command and data management system, a core segment simulator to simulate the Spacelab subsystem resources (mainly power and signals), and an experiment subsystem simulator to simulate experiment power loads and data interfaces. The core segment simulator was subsequently canceled during the 1977 program descoping. The electrical ground support equipment at the BTM facility is shown in figure 54.

In addition to the lack of definition of the Spacelab command and data management system and the Orbiter interfaces, a major problem faced by the BTM team was the lack of adequate software expertise. BTM leaned heavily on job shopping for this support from England, but satisfactory solutions were not found until the total program software needs were addressed in an integrated manner.

Initial plans called for two sets of EGSE to be developed and delivered to NASA, with a third set to be developed and retained in Europe for ESA's use. The third set of hardware eventually fell victim to ESA budgetary shortages and was cancelled. The first two sets were first tested at BTM, then used in the ERNO integration facility for verification of the engineering model and first flight unit. They were then sent to KSC for installation in the Operations and Checkout Building in support of the operations with the engineering model and flight units there. ESA managed to gather an additional set of hardware from its various co-contractors, which was adequate to check out the follow-on production flight unit at ERNO.

Once the initial problems with the EGSE and its related software were overcome, the Spacelab EGSE performed remarkably well, both in Europe and at KSC. Several times during the course of the program, arguments were made in favor of substituting the NASA Shuttle Launch Processing System (LPS) in place of the ESA


Experiment Subsystem Simulator
Spacelab
Orbiter Interface Adapter
Ground Power Unit
Data Uplinks
Data Downlinks
Remote Control
Interface Equipment
Computer and Peripherals
Operator Console
Recording and Timing

Item	Function	Status
Automatic Test Equipment	● Automatic test configuration ● Automatic test sequencing ● Data acquisition ● On and off line data processing Automatic command generation ● Automatic generation of stimuli and encoded data	Some components received by BTM Operator's console nearly complete and testing started
Ground Power Unit	● Simulates Orbiter power — Primary DC — Auxiliary busses to Spacelab and AFD — 400 Hz AC for AFD	Some components received by BTM and integration started
Orbiter Interface Adapter	● Simulates Orbiter poweer interface ● Simulates Orbiter signal interface ● Provides interface between Spacelab and Automatic Test Equipment ● Controls interface with ground servicers (water cooling, etc.)	Some components received by BTM and integration started
Experiment Segment/Pallet Simulator	● Simulates power loads for the electrical power system ● Simulates signals for the command and data management system ● Provides for level II checkout of core segment and igloo	Still in definition stage because of changes in related flight hardware
Core Segment Simulator	● Simulates Spacelab subsystem resources, mainly power and signals ● Supports Level III experiment hardware and software integration	Some components are identical to flight units and will be supplied by MATRA. Procurement of others started
Experiment Subsystem Simulator	● Simulates experiment power loads ● Simulates experiment data interfaces ● Used to simulate experiments for Spacelab checkout	Design completed and manufacture of some components started. Tests planned for early 1977

Figure 53. Above, a simplified block diagram of the electrical ground support equipment. The chart below details the status of the EGSE at the time of the second Preliminary Design Review (PDR-B).

Spacelab Automatic Test Equipment for NASA checkout, but it was difficult to argue with the fact that the ATE was being provided to NASA at no cost. There are still KSC personnel who feel that the LPS would have been a more efficient system to use, but they are forced to admit that the Spacelab ATE has done the job. Although many people deserve credit for the success of the EGSE program, Noel Parmentier and E. Naveau of BTM deserve special recognition for their leadership.

MODULE STRUCTURE

The basic structural elements of the Spacelab module are the two cylindrical segments, the end cones, and the internal floors and racks that make up the long or short module. Spacelab subsystem equipment was to be placed in two double racks at the forward end of the module and on a subfloor beneath the main floor. In addition, overhead supports were mounted on the module ceiling for attachment of the racks and for provision in each segment of up to seven overhead storage containers. All these module structures were produced by the Italian firm Aeritalia at its facilities in Turin (fig. 55) and Naples. The cylindrical segments were made of roll-formed waffle pattern aluminum alloy sheets welded at the seams, with end flanges of forged aluminum to join the segments to each other and to the end cones. These flanged joints are bolted for ease of assembly and disassembly.

Aeritalia faced unique challenges in developing the module structure. First, because of the large unsupported cylindrical structure, it was impossible to preserve the perfect symmetry of its circular shape without incurring serious weight problems. Therefore a special GSE "round-maker" or turnbuckle arrangement was devised to facilitate assembly and disassembly. Similar distortion problems were encountered in providing a pressure-tight mating surface in the top of the module shell for the window/viewport and airlock, which resulted in a buttressing of the supporting flanges for these openings. Development of the support trunnions and keel fittings was also a difficult task because these attachment fittings had to withstand not only the weight of the loaded module during ground handling but also the launch and landing loads imposed during flight. A unique part of this assignment was to provide a surface finish on the attachment fittings that would meet the very low friction coefficient demanded by the Shuttle so that as the Orbiter twisted and bent from changing pressure and thermal loads, the Spacelab would not transmit unacceptable loads into the Shuttle.

Another challenge facing Aeritalia was fracture criticality and stress corrosion of the aluminum alloy structures, which would experience repeated launch and landing loads during their lifetime and which would also be subject to repeated handling on the ground for a year or more for every week they would be in space. Analytical techniques in this regard were not as advanced in Europe as they were in the U.S., so technical experts from Marshall and U.S. industry consultants spent considerable time helping Aeritalia in these areas.

Aeritalia not only manufactured the module elements, it also conducted critical

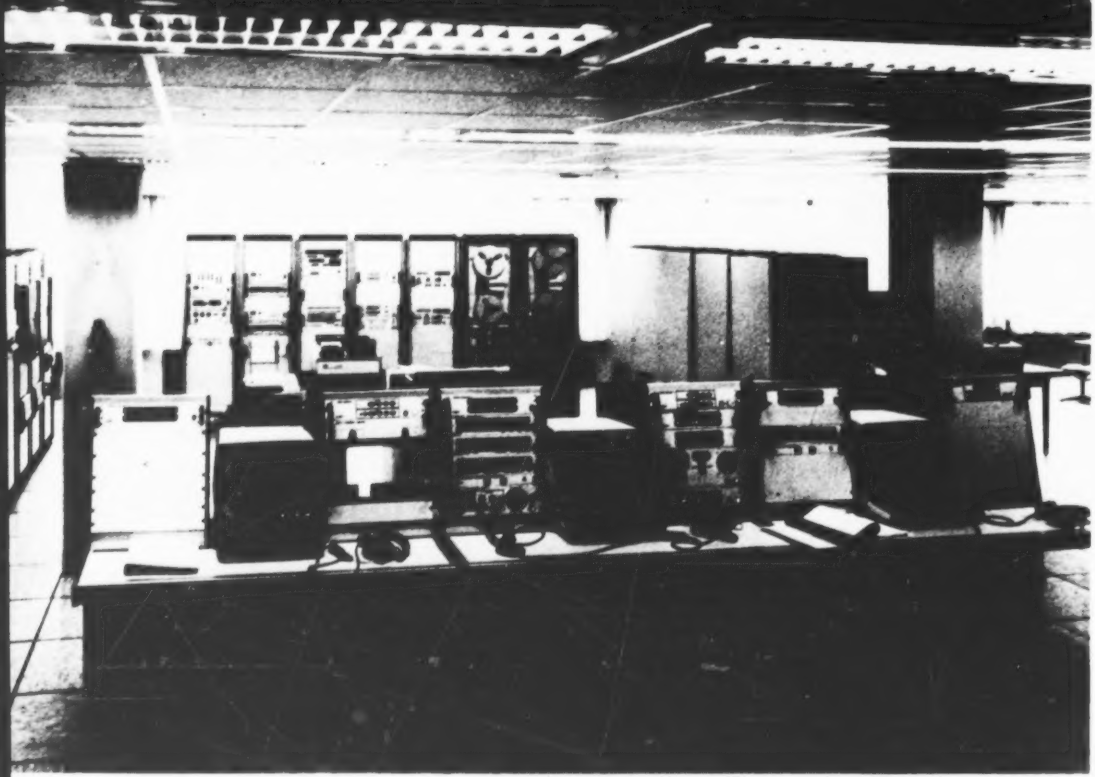


Figure 54. Spacelab electrical ground support equipment at the Bell Telephone Manufacturing facility in Antwerp, Belgium.

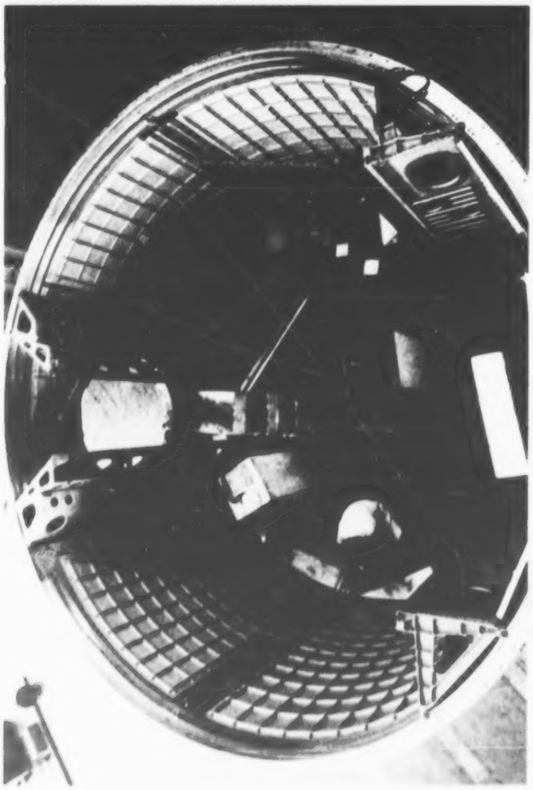


Figure 55. Segment of module being assembled at the Aeritalia facility in Turin, Italy, in 1976. Note the waffle skin and secondary support structures for the floor, racks, and overhead storage compartments.

tests to verify their performance. Certainly these were the largest diameter seals ever manufactured for application to space flight, which would be repeatedly disassembled and used again. Therefore, satisfactory tests of these seals were essential. Static and dynamic tests of the assembled module were also necessary to verify its pressure integrity and to provide cycle tests for fatigue and acceleration tests to prove it could withstand liftoff, landing, and transportation loads. By February 23, 1977, the module had successfully completed a series of limit, proof, and ultimate pressure (pressure differential of two atmospheres) testing at the Aeritalia facility in Turin (fig. 56). Finally, both vibration and acoustic testing were required to assure the module's ability to withstand these loads. Aeritalia's performance in meeting these and other challenges attests to the impressive leadership of Professor Ernesto Vallerani and Dr. Roberto Mannu. These two, ably assisted by Paolo Piantella and Giuseppe Viriglio, formed a formidable management team.

PALLET STRUCTURE

The pallet segments are identical modular units that can be mounted either separately or joined into pallet trains of two or three units. Their structural design is basically U-shaped to provide for use of the maximum volume within the Orbiter cargo bay. The design allows for mounting lightweight experiments on the inner panels or heavy equipment on hard points that transfer their loads to the primary pallet structure and thence to the Orbiter structure through the attachment fittings.

The pallet and module design teams took different approaches in mounting their respective structurs to the Orbiter. The module team selected what is called a determinant mounting, utilizing three support fittings to the Orbiter sill, which permits the structural analysts to solve by appropriate equations all reaction forces without using trial-and-error analysis. The Hawker-Siddeley Dynamics team (later a part of the nationalized British Aerospace conglomerate), located in Stevenage north of London, elected to mount the pallets or pallet trains using four symmetrical support fittings to the Orbiter sill in an indeterminant manner. Although this approach is more difficult from the analytical standpoint, it provides the benefit of being able to share the loads between the pallets and the Orbiter. In any case, both approaches proved to be satisfactory in practice.

As the program matured, the structural analyses became increasingly sophisticated and critical. Eventually it was necessary to perform coupled loads analyses considering the Spacelab and Orbiter as an integrated entity. Each time the Spacelab or Orbiter obtained new loads inputs from their respective structural test programs or analyses, these inputs were analyzed by Rockwell to determine what the integrated results would be. The results of this analysis, in turn, would be fed back to the Spacelab and Orbiter for the next iteration of structural analysis. Late in the Spacelab development program when Shuttle flight test loads were available, these continuing changes in loads would cause serious technical and programmatic problems for ESA and its contractors.

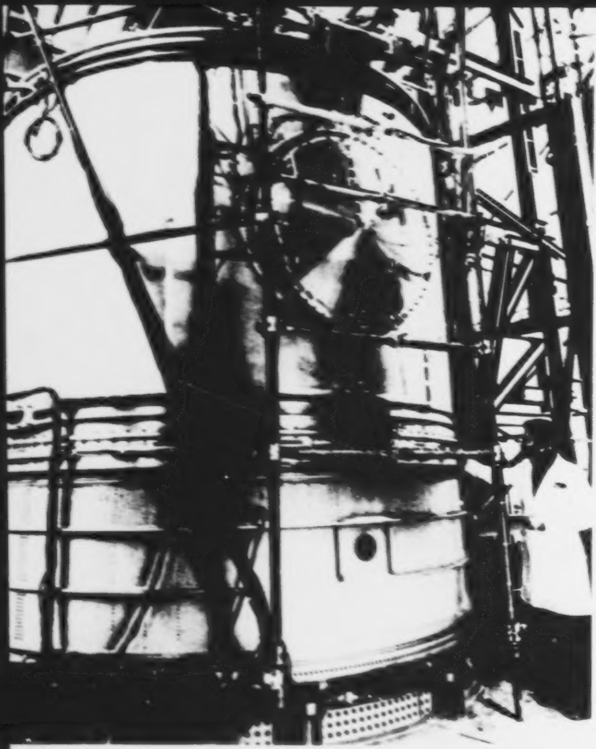


Figure 56. Spacelab development module configured for pressure testing at the Aeritalia facility in Turin.

One of the structural challenges for both the pallet and module designers was to allow for crash landing loads. The approach taken was a fairly conservative one, to design the Spacelab for a 9-g crash impact and 9.6 feet-per-second sink rate at touchdown. Spacelab was subsequently restricted to lower values because the Orbiter structure could not handle these loads. In actuality, the maximum g level anticipated in normal operation would be less than 3 g, and the sink rates would be 2–3 feet per second or less.

A particular problem faced by the pallet designer was to reduce the overall weight of the structure, which, as noted earlier, had posed a serious problem at the time of the Phase C/D go-ahead. One proposed solution was to replace the aluminum honeycomb panels on the pallet surfaces with panels made from lightweight composite materials. The difference in rates of expansion from thermal loads ruled out this approach. Therefore, very thin aluminum face plates are used on the panels (fig. 57), an approach which has caused problems for NASA in ground operations with the pallets because of the panels' fragility and the care with which attachment fittings and fasteners have to be handled. Torque wrenches have been replaced by extensiometers to derive every last ounce of strength out of the fasteners, which in turn must be replaced after each use. Although the pallets are designed to a normal safety factor of 1.4, there is little reinforcement or stiffening in local areas which would better accommodate repeated installation of fasteners and fittings. Moreover, because the structure deflects even with light loading, a more detailed load and structural analysis than originally expected must be made on every mission.

Another criticism levied at the pallet design is that many experimenters want their smaller equipment to be mounted at the sill level of the Orbiter in order to have

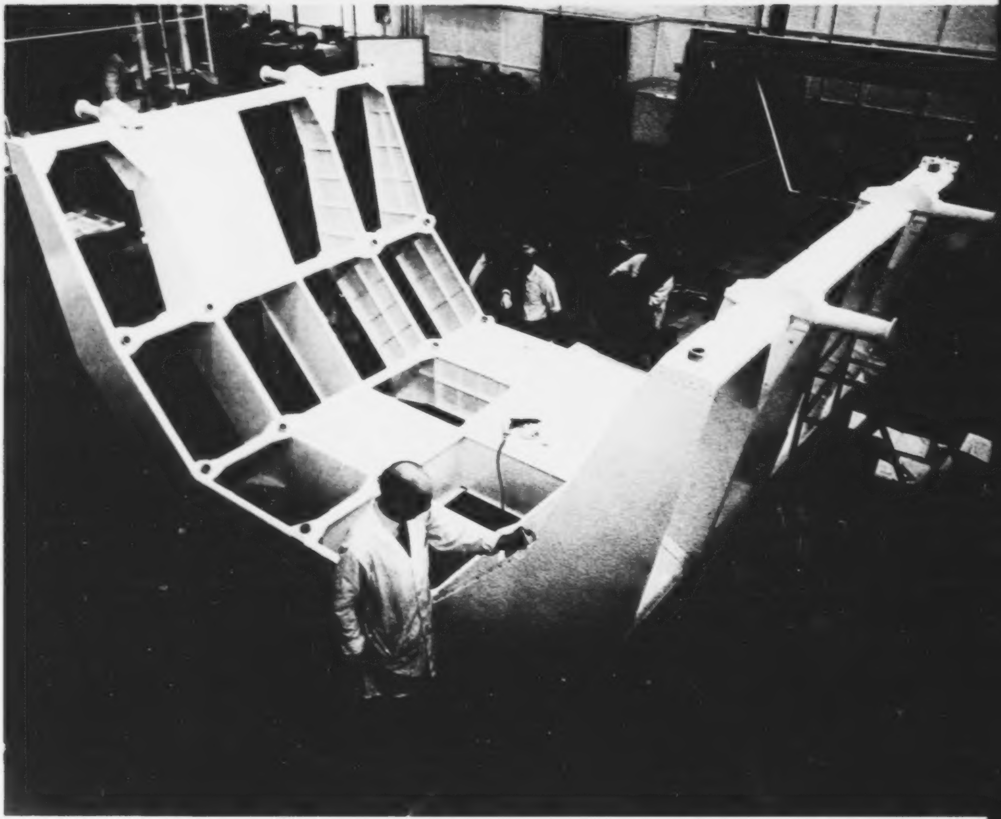


Figure 57. A technician attaches honeycomb panels to a pallet at the Hawker-Siddeley Dynamics facility in Stevenage, England, 1976.

better look angles. This requires fabrication of secondary structures to be mounted on the pallets. This requirement has also generated a whole family of competitive experiment carriers such as the SPAS (developed by MBB) and the MPESS (developed by MSFC and Teledyne-Brown). Both of these structures span the Orbiter cargo bay at the sill line to support small experimental equipment. Nevertheless, the Spacelab pallets are still the most effective shape for carrying larger experiments or the Instrument Pointing System and have proven to be an effective carrier for retrieval of failed satellites. Recovery of the PALAPA and WESTAR satellites in the November 1984 Shuttle mission, perhaps the most dramatic of the early Shuttle missions, involved using two Spacelab pallets to bring the satellites home.

Perhaps the most interesting challenge to the Hawker-Siddeley (British Aerospace Dynamics Group) team was the verification program to assure that all elements of the pallets, in their various applications, would meet performance specifications. The verification philosophy was based on a combination of analysis and test. The analyses included finite element models, dynamic models, detailed stress analysis, pallet modal surveys, fatigue and fracture mechanics analyses, and static analyses. Tests included pallet static tests of single and triple pallet trains; acoustic vibration tests of a single pallet; component level testing of panels, attachment fittings, hardpoints, and pallet/pallet joint; and tests at the detail level of panels, materials, and finishes (fig. 58). These tests and structural analyses were modified and reiterated as new results were received from within the pallet program or from external sources such as the Shuttle.

It was originally planned that the engineering model pallets would be used only for gaining familiarization with these Spacelab elements in ground-handling training exercises and in checking out the KSC workstands and integration procedures. In fact, some of the pallets to be delivered as part of the engineering model would have been used in the structural test program and were not considered suitable for flight application because of the stressful environment they had already experienced or because manufacture had been completed before final design specifications had been implemented. It was soon recognized, however, that some of these engineering model pallet structures could be suitable mounting devices (for limited weights and a reduced number of flights) for carrying experiments in the early Shuttle flight test period. It was first planned that there would be six Shuttle test flights and several of these could carry useful payloads, provided ESA would accept the idea of NASA using some of the engineering model pallets as experiment carriers. Thus was born the concept of the orbital flight test (OFT) pallets, of which more will be said later.

As with each of the other subsystem areas, recognition should be given to the British leadership in the pallet effort. Initially, Cliff Allen was the team leader for Hawker-Siddeley, but his untimely death early in the program required the selection of Basil Smith, who guided the team with dedication and skill for most of the remaining development phase of the program.

ENVIRONMENTAL CONTROL SUBSYSTEM

This important Spacelab subsystem provides sea-level pressure and a shirt-sleeve atmosphere for the Spacelab crew and their experimental equipment. The responsibility includes maintaining the pressure, temperature, humidity, and composition of the module air within specified limits, providing for the transfer of the heat loads generated by the module and pallets to the Orbiter thermal control system, limiting the heat flux in both directions between the module and its environment, and providing for fire detection and suppression in the module.

The design approach involved a careful marriage of the Orbiter and Spacelab subsystems (fig. 59). The Orbiter would provide makeup oxygen to the Spacelab, which in turn would provide its own source of makeup nitrogen as well as all the necessary components to regulate and distribute the air supply throughout the module and to remove excess moisture and carbon dioxide. One circuit of air flow would distribute air within the cabin of the module, and a second avionics loop would provide air supply to the racks for cooling of mounted equipment. The cabin and avionics air loops are cooled by passing the air through a heat exchanger which transfers the heat load to a flow of water. The water is then pumped through the Or-

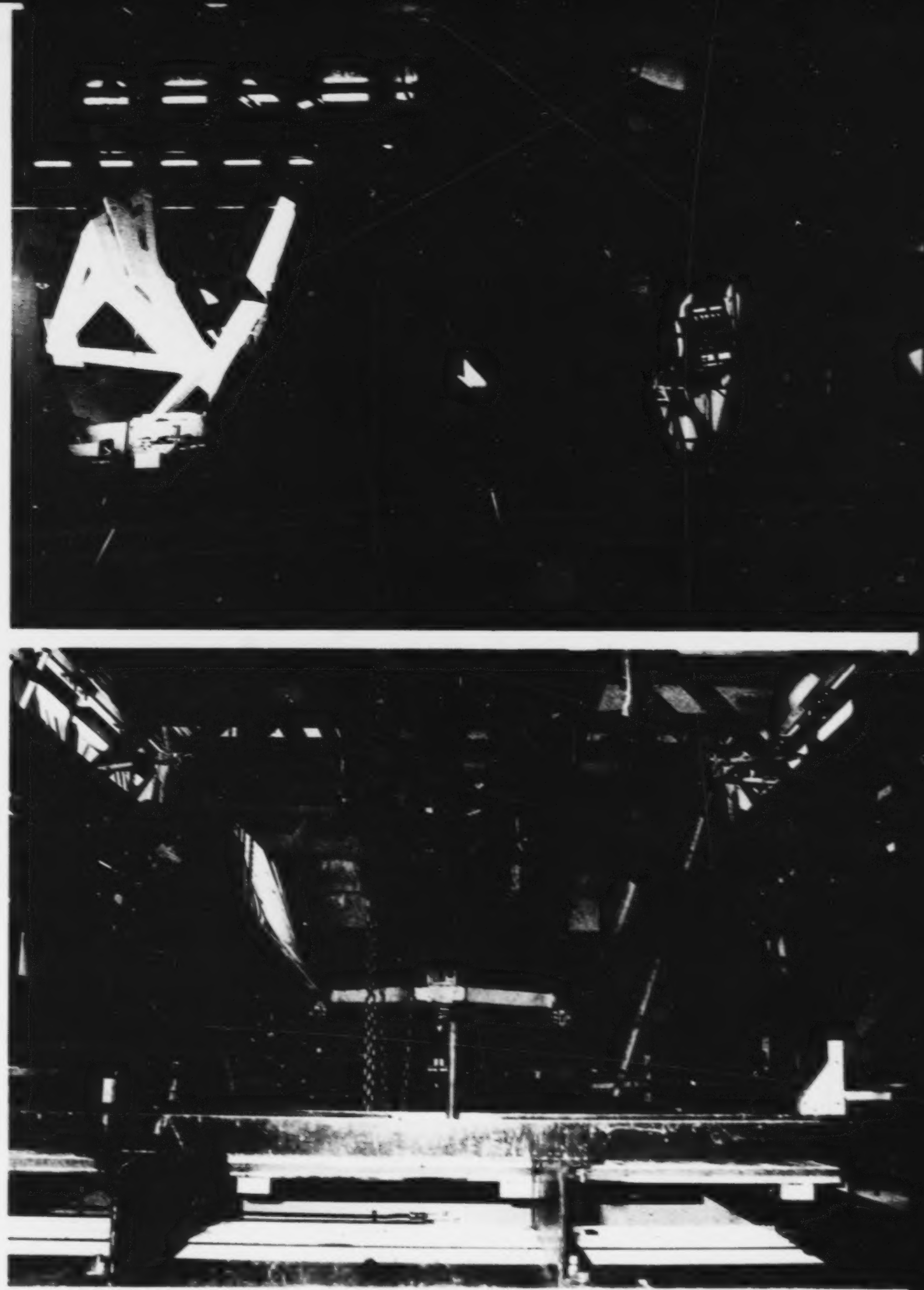


Figure 58. The Spacelab pallet verification program. The top photograph shows a pallet mounted for acoustic testing at IABG's facility near Munich, West Germany, in 1977. Below, a pallet is readied for structural testing at the Hawker-Siddeley Dynamics facility at Hatfield, England, in 1978.

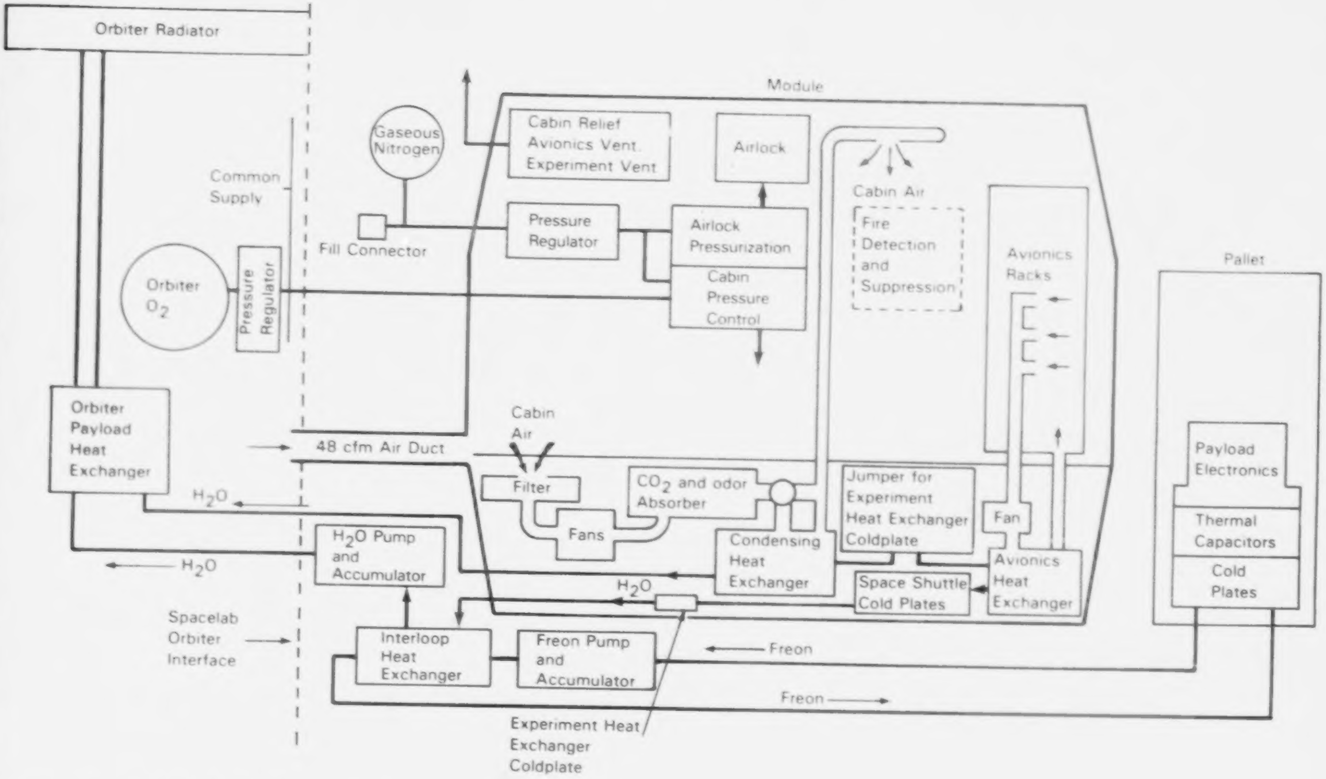

Orbiter Radiator
Module
Gaseous Nitrogen
Cabin Relief Avionics Vent. Experiment Vent
Airlock
Common Supply
Fill Connector
Pressure Regulator
Airlock Pressurization
Cabin Air
Fire Detection and Suppression
Avionics Racks
Pallet
Orbiter O$_2$
Pressure Regulator
Cabin Pressure Control
Orbiter Payload Heat Exchanger
Cabin Air
48 cfm Air Duct
Filter
CO$_2$ and odor Absorber
Fans
Jumper for Experiment Heat Exchanger Coldplate
Fan
Payload Electronics
Thermal Capacitors
Cold Plates
H$_2$O
H$_2$O Pump and Accumulator
Condensing Heat Exchanger
H$_2$O
H$_2$O
Space Shuttle Cold Plates
Avionics Heat Exchanger
Spacelab Orbiter Interface
Interloop Heat Exchanger
Freon Pump and Accumulator
Freon
Freon
Experiment Heat Exchanger Coldplate

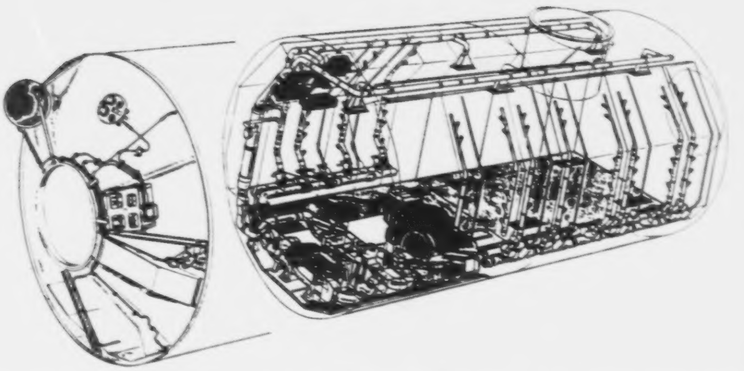
Figure 59. Simplified block diagram of the environmental control subsystem.

biter payload heat exchanger to transfer the total Spacelab heat load to the Orbiter for dissipation through its externally mounted radiators. While the experiments in the module rely mainly on air cooling, some of the basic Spacelab subsystem components were mounted on cold plates tied into the same water cooling loop. Heat loads from experiments and Spacelab subsystem equipment on the pallets are dissipated through cold plates using freon (because of its lower freezing point) as a working fluid rather than water, then transferred to the module water loop through an interloop heat exchanger or in the pallet-only mode, directly to the Orbiter heat exchanger. Finally, passive thermal blankets insulate the various Spacelab structural elements from the flow of thermal energy to or from the surrounding environment.

As mentioned, the responsibility for these critical elements of the environmental control subsystem was divided between Aeritalia for thermal control and Dornier System for environmental control and life support. Aeritalia, in turn, relied heavily on Microtecnica of Italy and Hamilton Standard of the U.S. in developing the active thermal control components. Dornier, for its part, received strong support from Hamilton Standard and also from ERNO and Nord Micro of West Germany and from Celesco, Brunswick, and Carleton Controls of the U.S.

Each contractor faced unique challenges in meeting the environmental control specifications. The Dornier team built a hard mockup of the Spacelab in its laboratory to simulate the environmental control and life support subsystem including the makeup and control of the atmosphere and the airflows within the module (fig. 60). Initially it had been planned that all subsystem and experiment equipment internal to the module would be air cooled by mounting it in standard 19-inch-wide, aircraft-type drawers in the racks and circulating the avionics cooling air through the racks. It was soon found to be necessary to mount most of the subsystem equipment on cold plates to provide more precise temperature control. An extra cold plate was provided for use by the experimenters. The remainder of the experiment equipment in the racks was cooled by the avionics air loop. Each rack had an inlet diffuser with a cutoff valve and a return duct with adjustable orifices through which the flow of air could be controlled. This posed a serious problem for balancing the flow among the various racks as the experiment heat loads changed from mission to mission and as experiments were turned on and off during a given mission. After considerable trial and error, Dornier developed a workable operational procedure for adjusting the airflow to the racks for each mission.

Within the igloo a similar change was made from air cooling to cold plate cooling for the subsystems mounted therein. It was found that the atmosphere leak rate from within the igloo could be maintained at such a low rate that an active air makeup system was not needed for missions up to 12 days in duration. On the pallet itself, pallet subsystems were moved from the pallet sill, where it was expected they could dissipate heat by radiation, to a cold plate on the pallet floor or lower sides. As many as eight additional cold plates could be mounted on the pallets for use by the experimenters, and four thermal capacitors were provided to store peak heat loads. Freon 21 was initially selected as the coolant because of its excellent thermal



Item	Produced by	Country	Status at PDR–B
Thermal Control	Aeritalia		
Active Thermal Control	Aeritalia		
Freon pump package	Hamilton Standard/ Microtecnica	USA/Italy	Development unit in test
Interloop heat exchanger	Microtecnica	Italy	Development unit in test
Experiment cold plates	Microtecnica	Italy	Development unit in test
Thermal capacitors	Microtecnica	Italy	Development unit being built
Subsystem cold plates	Microtecnica	Italy	Development unit being built
Experiment heat exchanger	Microtecnica	Italy	Identical with interloop heat exchanger
Passive Thermal Control	Aeritalia		
Module, pallet, and utility line insulation blankets	Aeritalia	Italy	Development units being built
Igloo insulation blankets	ERNO	W. Germany	In design
Environmental Control and Life Support Air Revitalization	Dornier	W. Germany	
Temperature and humidity assembly	Hamilton Standard	USA	Development unit in test
Water seperator	Hamilton Standard	USA	Development unit in test
Condensate storage tank	ERNO	W. Germany	Development unit being built
CO_2 control assembly	Hamilton Standard	USA	Development unit in test
Avionics heat exchanger	Nord Micro	W. Germany	Breadboard unit in test
Cabin fan	Hamilton Standard	USA	Development unit in test
Avionics fan	Nord Micro/Garret	W. Germany	Development unit in test
Smoke detection assembly (Orbiter common)	DS/Celesco	W. Germany (USA)	Development unit in acceptance test
Fire suppression system	DS/Celesco	W. Germany	Development unit in test
Overboard dumping system	DS	W. Germany	Development unit in test
Atmosphere Storage and Control			
Gaseous nitrogen tank assembly (Orbiter common)	Brunswick	USA	only flight units
O2/N2 control panel	Carleton	USA	Development unit in test
Cabin pressure relief assembly	Carleton	USA	Development unit being built
Experiment vent assembly	Carleton	USA	Development unit being built
Monitoring and control assembly	DS	W. Germany	Breadboard in test

Figure 60. Above, the layout of the environmental control subsystem in the Spacelab module. Major subsystem components are located under the floor in the core segment. The status of the environmental control subsystem hardware components at the time of the second Preliminary Design Review (PDR-B) is shown below.

properties for the extreme orbital thermal environment. Later, NASA switched to Freon 114 because of concerns about the toxicity of Freon 21.

Within the module, capability had to be provided for repressurizing the scientific airlock at least once a day with nitrogen and for providing an overboard venting system for experiments to discharge exhaust products or to obtain a needed vacuum vent. The carbon dioxide level is kept within safe limits by using replaceable lithium hydroxide cartridges which also contain activated charcoal to remove certain trace contaminants and odors. A condensing heat exchanger cools the air in the cabin loop below the dew point and the resultant condensate is removed by a motor driven rotary separator and stored. Perhaps the most important change to the environmental control subsystem was the addition of an active fire suppression system using HALON 1301 which could be activated by the crew from within the Spacelab or from the Orbiter and which had a double command method to prevent inadvertent use. Portable, hand-held fire extinguishers were also provided. As a final fire protection device, a cabin air dump capability was provided.

For passive thermal control, Aeritalia selected multilayer insulation (MLI) blankets to minimize the radiative heat exchange between the module and space as well as to the Orbiter cargo bay. The MLI consisted of 19 layers of double "goldized" Kapton and 20 layers of Dacron net separator, covered externally by Teflon-coated beta cloth and internally by double "goldized" 50-gauge polyamide Nomex reinforced sheet. The attachment to the module was devised to allow for adequate venting of the enclosed air between the Spacelab structure and the MLI during ascent and repressurization of the enclosed vacuum during reentry. Thermal tents of MLI were also provided by Aeritalia for the igloo and for pallet-mounted subsystems.

Despite all the design precautions, analyses of certain critical mission conditions showed there could be environmental problems. For example, with the Orbiter cargo bay faced away from the Sun (no direct solar radiation on the Spacelab), there was the possibility that the cabin air temperature could be below the desired minimum and condensation could form on the module walls. The so-called "cold-case fix" was implemented to bypass the heat exchanger with part of the air flow and eliminate the problem. At the other extreme, when the Spacelab faced directly into the Sun for extended periods, there was concern that solar radiation could be trapped between the module or pallet and the Orbiter cargo bay, thus driving the local temperature beyond acceptable limits. Consideration was given to blocking these openings between the Spacelab and the Orbiter or to impose an operational constraint to limit the period of time in which the Spacelab would be held in this attitude. In practical application, the environmental control subsystem performed flawlessly in its first mission: the atmospheric pressure and temperature were extremely stable and the Spacelab 1 crew had nothing but praise for the Spacelab environment. In addition to those already recognized for their leadership to the overall Aeritalia team, it is appropriate to single out Anton Drtil, Juergen Spintig, and Otto Mayer, the Local Project Managers for the ECLS team at Dornier, who deserve special recognition for the success of this critical subsystem.

COMMAND AND DATA MANAGEMENT SUBSYSTEM

No subsystem of the Spacelab was more challenging or more complex than the CDMS, which was assigned to MATRA, a well-established French electronics firm located in Velizy, near Paris. The functions of the CDMS, diagrammed in figure 61, were to provide commands to the Spacelab subsystems and experiments from the ground, from the aft flight deck of the Orbiter or from within the Spacelab module, to process low-rate data from the Spacelab and its onboard experiments, to transmit multiple channels of wideband scientific data, to telemeter both low-rate and wideband data to the ground, and to provide mass memory storage for the central computers and storage of high-rate digital data for periods of time when the Spacelab was out of sight of the Tracking and Data Relay Satellite.

The most important early change in the data subsystem was the addition of the high-rate multiplexer to provide for simultaneous handling of up to 16 channels of 16-megabit-per-second data. This critical component was developed by MBB in cooperation with Martin Marietta, which developed its companion demultiplexer for sorting out the data when they reached the ground. Other key components were the onboard computers, data display/keyboards, and input/output and interconnecting stations developed, respectively, by the French firms of CII, Thomson-CSF, and MATRA. The mass memory unit and the high-rate digital recorder was developed by Odetics of the U.S. The remote acquisition units, which interfaced all equipment to the data bus, were provided by SEL of West Germany, and the voice digitizer and intercom equipment were built by the West German firm AEG-Telefunken. The status of the subsystem components at the time of the PDR-B is shown in figure 62.

The Spacelab command and data management subsystem operates as an extension of the Orbiter telecommunication system. Thus data generated by the Spacelab or its experiments are acquired by the CDMS and multiplexed in low-rate housekeeping and high-rate scientific data streams for transmission by the Orbiter. The Orbiter, in turn, communicates to the ground station at White Sands, New Mexico, via S-band or Ku-band through the geostationary satellites of the Tracking and Data Relay Satellite System. From White Sands, the data are relayed to the Payload Operations Control Center at Houston and to the Spacelab Data Processing Facility at the Goddard Space Flight Center in Greenbelt, Maryland.

As mentioned, the CDMS was the subject of study by several working groups and also received more than its fair share of attention at each of the major program reviews. Earlier chapters related some of the arguments about the activation of the Spacelab subsystems and the degree to which the Orbiter general purpose computer would be tied into the Spacelab system. Gradually, however, this important subsystem began to take shape in two important elements: the data processing assembly and the high-rate data assembly. The data processing assembly was divided into separate parts for experiments and subsystems, each part having a computer, an in-

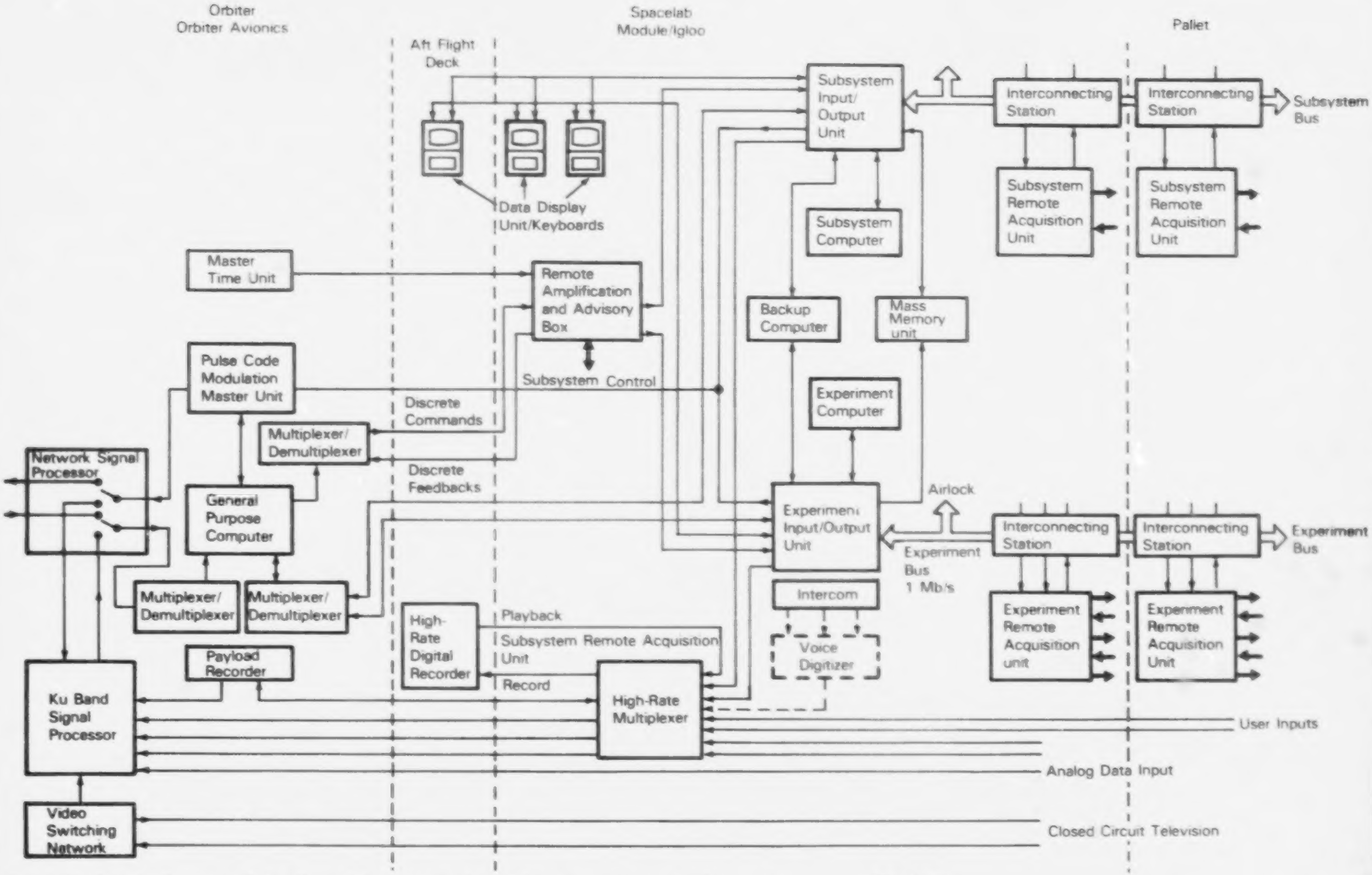

Orbiter
Orbiter Avionics
Aft Flight Deck
Spacelab Module/Igloo
Pallet
Subsystem Input/ Output Unit
Interconnecting Station
Interconnecting Station
Subsystem Bus
Subsystem Remote Acquisition Unit
Subsystem Remote Acquisition Unit
Data Display Unit/Keyboards
Subsystem Computer
Master Time Unit
Remote Amplification and Advisory Box
Backup Computer
Mass Memory unit
Pulse Code Modulation Master Unit
Subsystem Control
Discrete Commands
Experiment Computer
Multiplexer/ Demultiplexer
Network Signal Processor
Discrete Feedbacks
Airlock
General Purpose Computer
Experiment Input/Output Unit
Interconnecting Station
Interconnecting Station
Experiment Bus
Experiment Bus 1 Mb/s
Multiplexer/ Demultiplexer
Multiplexer/ Demultiplexer
Intercom
Experiment Remote Acquisition unit
Experiment Remote Acquisition Unit
High-Rate Digital Recorder
Playback
Subsystem Remote Acquisition Unit
Voice Digitizer
Payload Recorder
Record
Ku Band Signal Processor
High-Rate Multiplexer
User Inputs
Analog Data Input
Video Switching Network
Closed Circuit Television

Figure 61. Block diagram of the Spacelab command and data management subsystem.

put/output unit, and a 1-megabit-per-second digital data bus routed throughout the Spacelab with standard interface units (remote acquisition units). The three keyboards and displays and the mass memory unit were shared by the two parts. The role of the data processing assembly was to acquire data and to distribute timing and commands via the data bus and to interface with the Orbiter multiplexer/demultiplexers (MDMs), the pulse code modulation master unit, and the master timing unit. The high-rate data assembly consists of the high-rate multiplexer, the high-data-rate recorder, and the demultiplexer and high-data-rate recorders on the ground. The role of the high-rate data assembly is to acquire data directly from the experiments and to time division multiplex these data into a composite data stream of up to 48 megabits per second which can be transmitted to the ground using the Ku-band communication system. Some low-speed data can also be merged in this data stream, and digitized voice and timing data can be added.

In addition to the technical challenge of the overall subsystem and its add-on multiplexer capability, probably the most difficult component to develop was the high-data-rate recorder. Space recorders have been notorious for their lack of reliability, and many questions were raised about the one proposed for Spacelab with its capability to record data at the heretofore unheard-of rate of 32 megabits per second for 20 minutes duration. Where should it be located? Should a redundant unit be carried? Was tape change necessary? It was finally determined to carry only one unit but to have an astronaut Mission Specialist trained in making a tape change. After the jamming and subsequent unjamming of the recorder during the first Spacelab mission, this requirement for the Mission Specialist's knowledge of the system for tape change would turn out to be a very fortuitous decision. Now the

Item	Produced by	Country	Status at PDR–B
Onboard Computers	CII	France	Ground version operating
Mass Memory Unit	Odetics	USA	Development model available
Input/Output Unit	MATRA	France	Breadboard unit in assembly
Data Display Unit/Keyboard	Thomson-CSF	France	Breadboard unit completed
High-Rate Multiplexer	MBB	W. Germany	ECP in definition
High-Rate Digital Recorder	Odetics	USA	Breadboard unit in assembly
Interconnecting Stations	MATRA	France	Breadboard unit completed
Remote Acquisition Units	SEL	W. Germany	Breadboard unit completed
Voice Digitizer	AEG-Telefunken	W. Germany	ECP in definition
Intercom Equipment	AEG-Telefunken	W. Germany	Breadboard unit completed

Figure 62. Status of command and data management subsystem hardware at the time of the second Preliminary Design Review (PDR-B).

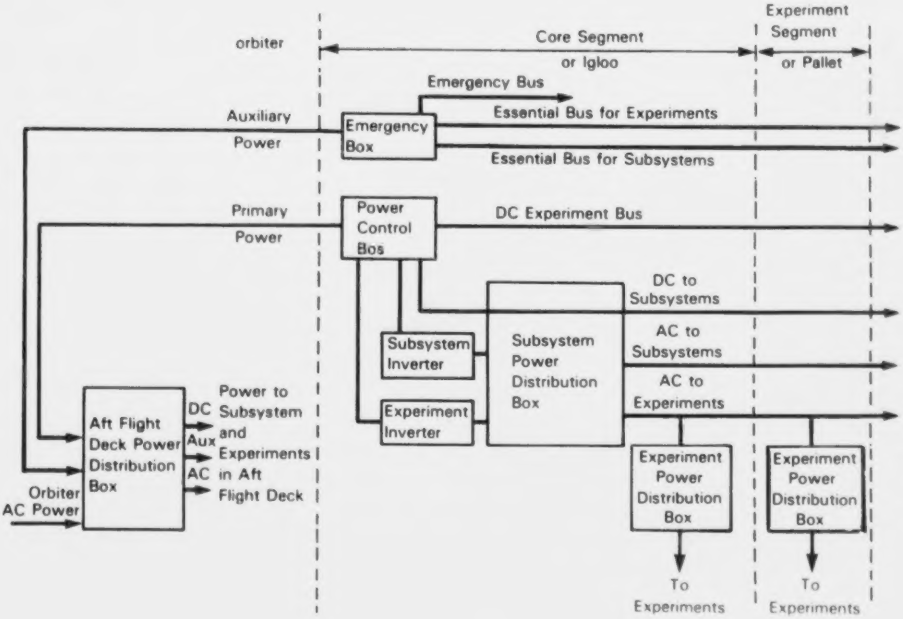
question would be raised whether the concurrent decision to place the recorder on the pallet in a pallet-only mission (probably one of our poorer decisions) should be reexamined so as to facilitate crew accessibility. Of course, if a relay satellite were always within view of the Spacelab, this recorder would not be necessary. But given the ultimate planned capability of only two operating satellites, there would always be short periods in which the recorder would be needed. The actual situation of only one satellite operating during the early Spacelab missions and the increasing number of high-data-rate experiments gave added importance to this critical component.

Unlike the multiplexer and the recorder, the intercom system received little attention from top management during this early period. The system that was selected provided only a single channel for both transmitting and receiving. The early Spacelab mission astronaut crews, accustomed to the more flexible system used in the Orbiter which provided for simultaneous monitoring of several channels, objected to the restrictive Spacelab approach. Some of the ESA avionics experts, however, are convinced that the Spacelab system works well provided it is used correctly and that the problems the astronauts encountered could have been avoided if JSC had had a working model of the Spacelab intercom system at its facility.

Although there certainly were some shortcomings within the command and data management subsystem, the overall approach taken for this most complex (with the possible exception of the Instrument Pointing System) of the Spacelab subsystems proved to work remarkably well. The leadership of Andre Rampillon and Francois Vignes, Local Project Managers for MATRA during the development period, deserves much of the credit for this accomplishment.

ELECTRICAL POWER DISTRIBUTION SUBSYSTEM

If there was a straightforward design and development area within the Spacelab program, this was probably it. On the other hand, the electrical harness is traditionally a major weight driver and so intimately tied to the details of the structural design that it is difficult to fabricate separately. The usual American practice is to have the prime contractor assemble the harness. Once again, the European approach was different. AEG-Telefunken had the assignment of taking the electrical power provided by the Orbiter and delivering it, as needed, to the various Spacelab subsystems and onboard experiments. The layout of the electrical power distribution subsystem is shown in figure 63. Shuttle Orbiter power was to be provided by three fuel cells generating electrical power from the chemical reaction of hydrogen and oxygen. On orbit, the output of one of these fuel cells could be dedicated to the Spacelab and would provide 7 kw of DC power at 28 volts. Peak output of 12 kw could be provided for 15 minutes in a 3-hour period, the limits being set by the ability of the Orbiter to reject the attendant heat load. The total energy for a given mission would depend on the quantity of hydrogen and oxygen available for the fuel cells. On a normal mission, approximately 300 kwh are available to experimenters in a module configuration and 550 kwh in the pallet-only configuration. Plans called


orbiter
Core Segment
or Igloo
Experiment
Segment
or Pallet
Emergency Bus
Auxiliary
Power
Emergency
Box
Essential Bus for Experiments
Essential Bus for Subsystems
Primary
Power
Power
Control
Bos
DC Experiment Bus
DC to
Subsystems
Subsystem
Inverter
Subsystem
Power
Distribution
Box
AC to
Subsystems
AC to
Experiments
Experiment
Inverter
Power to
Subsystem
and
Experiments
in Aft
Flight Deck
DC
Aux
AC
Aft Flight
Deck Power
Distribution
Box
Orbiter
AC Power
Experiment
Power
Distribution
Box
Experiment
Power
Distribution
Box
To
Experiments
To
Experiments

Item	Status
Aft Flight Deck Power Distribution Bos	Concept redefined, ECP in preparation
Power control Box	Breadboard model completed
Electripal Power Distribution Subsystem Monitor and Control Panel	Breadboard model completed
Inverters	Breadboard model completed
Subsystem Power Distribution Box	Development model nearly completed
Experiment Power Distribution Box	Breadboard model completed
Experiment Power Switching Panel	Breadboard model completed
Emergency Box	Breadboard model completed
Lighting	Breadboard model completed
Wiring	Final definition

Figure 63. Above, a simplified block diagram of the Spacelab electrical power distribution subsystem. Below, the status of the subsystem hardware at the time of the second Preliminary Design Review (PDR-B).

for the availability of up to five additional reactant kits to be carried within the cargo bay, each of which would provide 840 kwh of energy.

A series of individualized components was developed to meet various Spacelab needs. In addition to using the DC power at 28 volts, inverters were provided to deliver 3-phase AC power at 400 Hz. Built-in control and regulation circuits protect the inverters and consumers against overvoltage and overcurrent. An emergency box was provided to supply 28-volt DC power to Spacelab subsystems and experiments, according to their criticality, as emergency or essential power. A monitoring control panel provides control of all valves and sensors in the environmental control subsystem and the thermal control subsystem and signal conditioning for other special needs. The main power conditioning, distribution, and control of the power from the Orbiter via the primary feeder is performed in the power control box, which includes a shunt regulator to limit the main bus voltage to 32 volts and melting fuses against short circuits on the feeders. A subsystem power distribution box distributes the DC and AC power into subsystem-dedicated feeders. One to four experiment power distribution boxes provide distribution, control, and monitoring for Spacelab experiments. Experiment power switching panels, in turn, provide for the branching and switching of DC and AC power from the dedicated distribution boxes to specific experiments. One final power distribution box is located in the Orbiter aft flight deck to provide power for Spacelab subsystem equipment and experiments located there. All these components were developed by AEG, with the exception of the subsystem power distribution box, which was built by Terma in Denmark. AEG also assembled the wiring harnesses, and INTA of Spain provided lighting equipment for the interior of the Spacelab module.

As indicated, the electrical power distribution subsystem was relatively free of development problems. There were some initial concerns about the power factor correction for the water and freon pumps in order to bring their AC power consumption within the capacity of the subsystem inverter. Another possible problem was the inrush current for these pumps which could exceed the capacity of the inverter, leading to low voltage for the other inverter loads. The adequacy of lighting within the module was also of some concern, since considerable power savings could be achieved by reducing the level of illumination. Probably the major development problem encountered in this early period was when wiring harnesses refused to fit in the module of the engineering model. Arguments ensued about the adequacy of three-dimensional jig boards used by AEG, but the problem was soon resolved.

Throughout the life of the program, the most serious challenge posed by the power subsystem was to provide adequate power to Spacelab users. Their appetite for electrical power, as for weight, was insatiable. On the other hand, it could be argued that the basic Spacelab required more than its share of the available power. Of the 7 kw provided from the Orbiter, basic Spacelab subsystems and mission-dependent equipment could require as much as 5 kw in a module configuration and 2 kw in the pallet-only mode, leaving only 2 kw and 5 kw for the experimenters. Efforts were made to reduce the power demands of the Spacelab subsystems, but this remained a limiting factor for Spacelab users. The only answer is to tailor the mission so as to minimize the power demands of mission-dependent equipment and to meet the needs of high-power instruments by switching off other instruments.

Despite these shortcomings, the electrical power distribution subsystem was the least troublesome of all the Spacelab subsystems. The cooperation and responsiveness of the AEG team in Hamburg under the leadership of Heinz Koebel, Matthias Rahmann, and Peter Paulsen deserve special recognition.

IGLOO AND UTILITY SUPPORT STRUCTURES

This equipment, the responsibility of SABCA in Brussels, received more than its share of design modifications. Designed to accommodate the Spacelab subsystems in the pallet-only mode, the igloo changed in size and in orientation from horizontal to vertical. The subsystems eventually outgrew the igloo, and debates continue to this day as to whether individual, hermetically sealed boxes should have been used for the various subsystem components instead of the igloo. One specific example indicates this might have been a very expensive and heavy way to have gone. This was the special housing developed in the U.S. for the high-data-rate recorder to be mounted directly to the pallet. As shown in figures 64 and 65, the primary igloo structure is a cylindrical, locally stiffened shell made of aluminum alloy forged rings, closed at the lower end and with a mounting flange at the top. It is mounted to the forward end frame of the foremost pallet. The cover is also a cylindrical shell of aluminum alloy, closed at the top, which mates to the top flange of the primary structure like an inverted garbage can. Subsystem equipment is mounted on a secondary structure which is hinged at the cover mating line to permit access to the bottom of the secondary structure. Penetrations to the igloo are provided for feedthrough of utility lines and for pressure relief.

The principal concern posed by the igloo during its early development period was whether it could maintain a suitable pressure environment for the equipment it contained without some kind of makeup gas supply. It was desired to avoid such a system in order to simplify the design and operation of the igloo. One proposal was to overpressurize the igloo before liftoff to provide additional time on orbit, but this was not looked at with favor by NASA launch operations people for obvious safety reasons. Eventually it was demonstrated that the seals provided an adequate barrier for leakage so that the igloo pressure environment would be satisfactory for missions up to 12 days duration.

In addition to the igloo, SABCA developed the utility support structures to carry the fluid lines and wiring harnesses between the module and an attached pallet or between separately mounted pallets. These cantilevered support mounts varied in length from 160 to 750 millimeters (6 to 30 inches) depending on the size of the gap to be spanned.

All in all, SABCA played a small but key role in Spacelab development, particularly for providing the pallet-only capability. Although there were many delays in the delivery of the SABCA-developed hardware, certainly the many changes in specifications and requirements deserve much of the blame for these problems. A more dedicated Local Project Manager than Michel C. Kneip, who directed the SABCA effort from start to finish, would have been difficult to find.

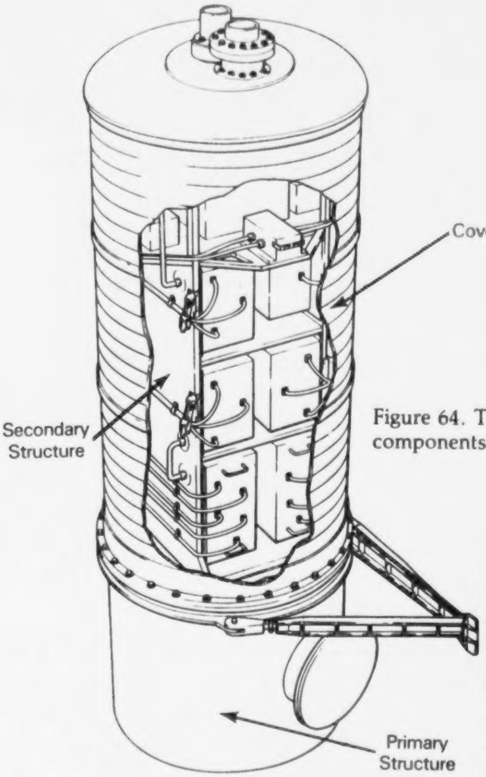

Cover
Secondary Structure
Primary Structure

Figure 64. The Spacelab igloo, with cutaway showing system components mounted on a secondary structure.

Figure 65. Igloo structure ready for transport to ERNO from the SABCA facility in Brussels, Belgium, May 1980.

SCIENTIFIC AIRLOCK

The 1-meter-diameter airlock, designed to permit deployment of experiments from within the module to the external environment, was assigned to the Fokker division of VFW located at Schiphol Airport near Amsterdam (fig. 66). Key to its design was the fact that the operation would be completely mechanical, thus avoiding the pitfalls of any electrical, hydraulic, or pneumatic malfunctions. Initially there were to be two versions, one of 1-meter length and the other 1.5 meters in length, but, as reported earlier, the larger airlock was deleted from the program.

Fokker subcontracted some accessory electronic components of the airlock to AEG and the manufacture of the airlock structure to Aeritalia. This cylindrical shell was manufactured from two large aluminum roll ring forgings, machined to shape and welded together. It is closed at both ends by circular honeycomb hatches, the outer one hinged and the inner one completely removeable. Experiments up to 100 kg in weight can be accommodated in the airlock, attached to a sliding table which can be extended almost 1 meter outside the airlock and 0.68 meter inside the module for servicing. Fokker incorporated mechanical and electrical interlocks to prevent dangerous sequences such as having both hatches open simultaneously. Unfortunately, one consequence of an elaborate interlock system to prevent hazardous conditions is to make it more likely that it will not operate in nonhazardous conditions. Despite the successful operation of the airlock in the Spacelab 1 mission, the interlocks may have contributed to the jammed scientific airlock on the Spacelab 3 mission. Both signal and power lines were provided for operation of the experiments in the airlock. A lamp is provided for illumination within the airlock, and heaters, surface coatings, multilayer insulation, and a removable thermal shield provide thermal control. The pressure in the airlock is controlled by a manual selector four-way vent valve which exhausts the airlock to the space environment or repressurizes the airlock from the nitrogen supply for at least seven cycles.

The most difficult challenges for the Fokker team were to develop a system that would meet the relatively ill-defined requirements of potential users, that would be acceptable for operation by the crew, and that would be completely safe. Since the airlock was the only portion of the Spacelab (other than experiment equipment) which would project beyond the Orbiter cargo bay envelope, it was essential that the experiment platform be capable of retraction and the airlock hatch closed so that the cargo bay doors could be closed for reentry. Initially it was thought the Orbiter manipulator arm could be used as a backup device to jettison the airlock experiment table and hatch, but since this arm may not be flown on all Spacelab missions, an extravehicular (EVA) approach was implemented. Thus if the normal mechanical controls will not work, an EVA crew member can try to restore the table and close the hatch. Failing that, the astronaut can jettison either the table or hatch, or both.

Another problem for the airlock team related to the continuing saga of keeping the hole round in the shell of the module. During the course of development it was necessary to stiffen the airlock because of deformations that occurred. In the Spacelab 1 mission, higher than expected forces were required on the lever to lock the airlock hatch, indicating that this problem may still persist to some degree. In any case, it did not prevent the operation of the airlock. All in all, the Fokker team under Local Project Managers Evert Benes, Johan Tigchelaar, Rients Swart, and Rob de Wit successfully overcame a number of unusual challenges to build a unique capability for Spacelab users.

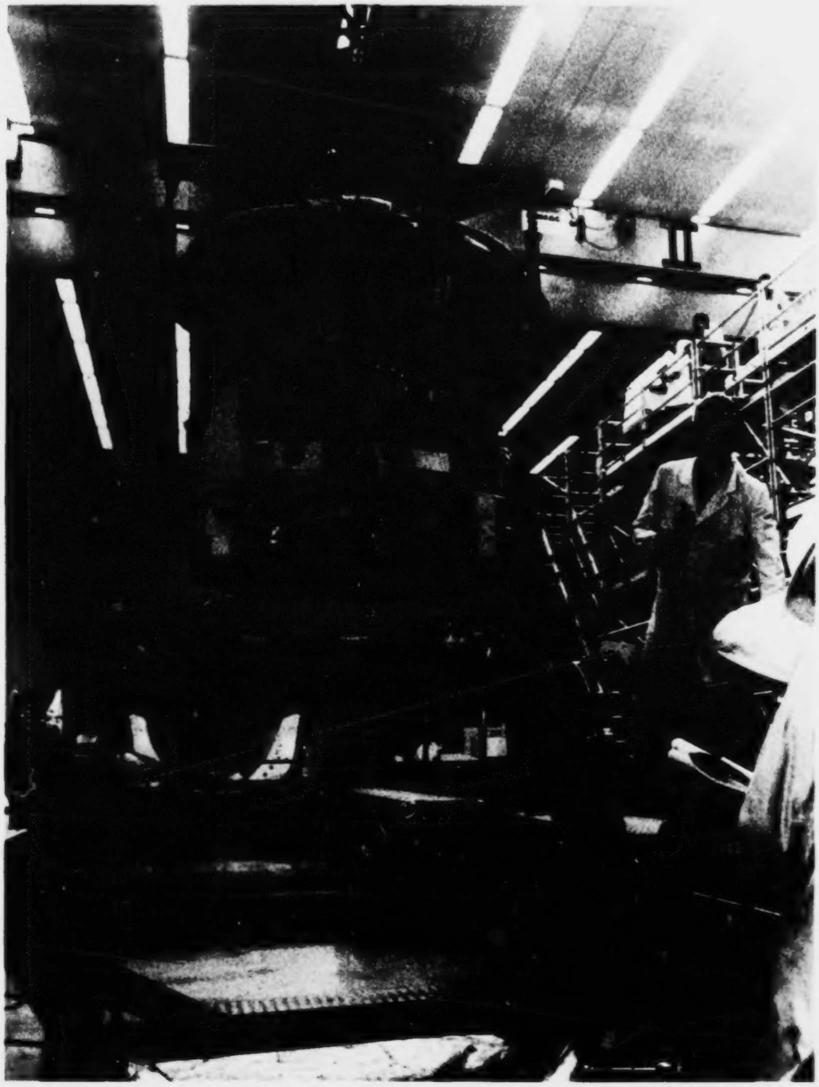


Figure 66. Fokker scientific airlock being mounted in the engineering model at ERNO in 1980.

OTHER SUBSYSTEMS

Most of the other subsystem elements were developed by ERNO as part of its prime contractor role. For example, a number of components were designed and incorporated into the Spacelab to improve crew habitability. One rack was modified to provide a workbench for the onboard crew, with suitable utility drawers, tools, electrical outlet, restraints, filing cabinets, and tissue dispensers for general work activities. Lighting was installed in a recessed area above the primary work surface. Handholds were provided for internal and external work by the crew with suitable loose item restraints, storage containers, waste bags, and an equipment locator system.

In order to provide the crew with a safe environment, a caution and warning system was developed. Smoke sensors trigger an alarm system and interface with a display unit which pinpoints the location of the problem and which is connected directly to the fire suppression system. Total pressure and partial pressure of oxygen sensors provide an alert in the event of dangerous conditions in either of these areas. Similar sensors alert the crew to hazardous conditions present if a water pump or avionics fan stops working, reducing the cooling capacity, or if power is turned on to a rack in which the cooling has been shut off. Other safety devices include pressure relief valves, portable fire extinguishers, portable oxygen masks, emergency power and lighting, and redundant seals between the Spacelab pressurized compartments and the space environment.

Capabilities of an entirely different nature are provided by the high-quality optical window and the viewport assemblies. The optical window was supplied by NASA, using a backup window developed for Skylab, to permit precision optical observations from inside the module. The window consists of a single 4.1-cm-thick pane of BK-7 glass of rectangular shape (41 × 55 cm) enclosed in a molded seal and supported by a flexible spring system in an aluminum frame. A heater system controls window temperatures to minimize thermal gradient and maintain optical performance. This window is mounted in a 1-meter-diameter hatch in the top of the module along with a viewport assembly 30 cm in diameter of somewhat lesser optical performance (fig. 67). A second identical viewport is permanently located in the aft end cone of the module, providing visibility for the crew in the direction of any pallets onboard. Experiments and cameras can be attached to the optical window or viewport flanges, and protective covers are provided on both internal and external surfaces.

By listing miscellaneous components under development by ERNO and its supporting contractors, I do not mean to infer that this was all that ERNO was doing during this phase of the program. In addition to the usual project management activities, ERNO continued its systems engineering and product assurance activities,

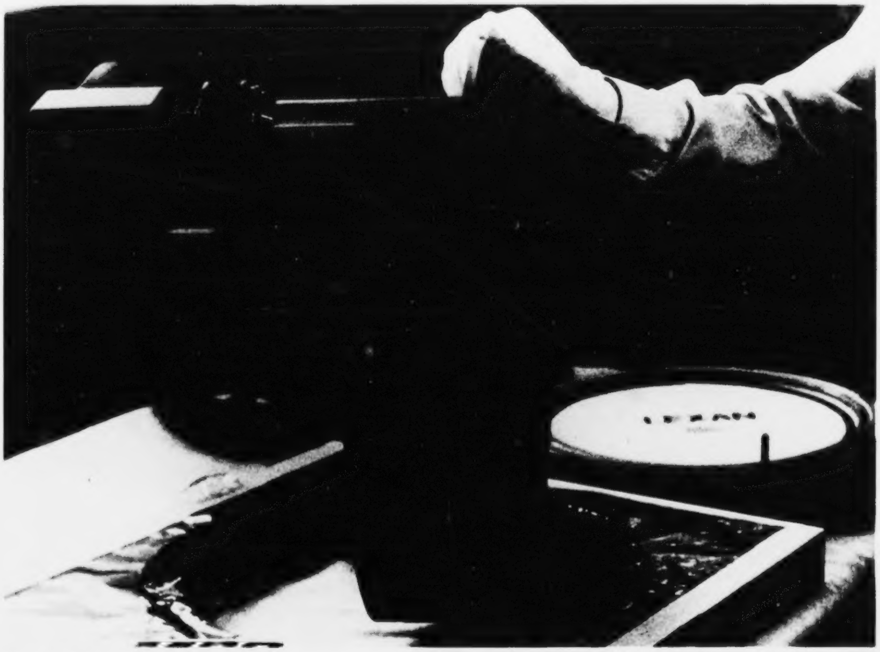


Figure 67. **Engineering model viewport ready for installation in the top of the Spacelab module or in the aft end cone, 1980.**

operations and logistics planning, assembly of mockups, and, most important, preparation for integration of the hardware elements as they arrived at Bremen. The Integration Hall, the foundation of which was laid barely a year earlier, was ready for receipt of hardware by early 1976. The most impressive feature of the new facility was an immense clean room for assembly and checkout of the very large pieces of Spacelab hardware which could be laid out side by side in two parallel lines, together with considerable space for supporting equipment, scaffolding, and preparation areas. Adjacent rooms provided supporting work areas, shops, offices, an auditorium, and electrical ground support equipment space. Little did we realize that space in this seemingly spacious facility would soon be at a premium.

One of the first actions to take place in the Integration Hall was assembly of a development fixture. This open-grid structure provided a framework for mounting a simulated module subfloor and main floor for attachment of subsystem components to check the three-dimensional relationships of these critical elements and the interconnecting electrical harnesses and fluid plumbing lines. Thus the way was prepared to have the engineering model ready for shipment to NASA by late 1978. This schedule would prove to be optimistic by a matter of 2 years.

ELECTRICAL SYSTEM INTEGRATION (ESI)

During the next year, the clean room of the ERNO Integration Hall remained primarily a promise of things to come. Gradually, however, an assemblage of electrical components began to take shape. Racks of hardware from AEG, BTM, and other contractors were being put together for the first time to provide a breadboard model of Spacelab's major electrical and avionics functions. The equipment, some of which is shown in figures 68 and 69, would be used in a series of system-level tests designed to demonstrate subsystem compatibility, hardware-software compatibility, and initial system activation and performance. It would also be used to develop and verify test procedures and troubleshooting, so essential to the successful checkout of the engineering model and the flight unit.

Along with each component received from the co-contractors for incorporation into the ESI came a unit tester for troubleshooting within the component in the event of problems or a failure. The unit testers would become important bargaining chips for later negotiations between NASA and ESA. In particular, NASA wanted such test equipment available at KSC for the Spacelab operational phase.

ESI planning proposed five major tests: T 800—an electrical power distribution subsystem self-test, T 810—a command and data management subsystem self-test, T

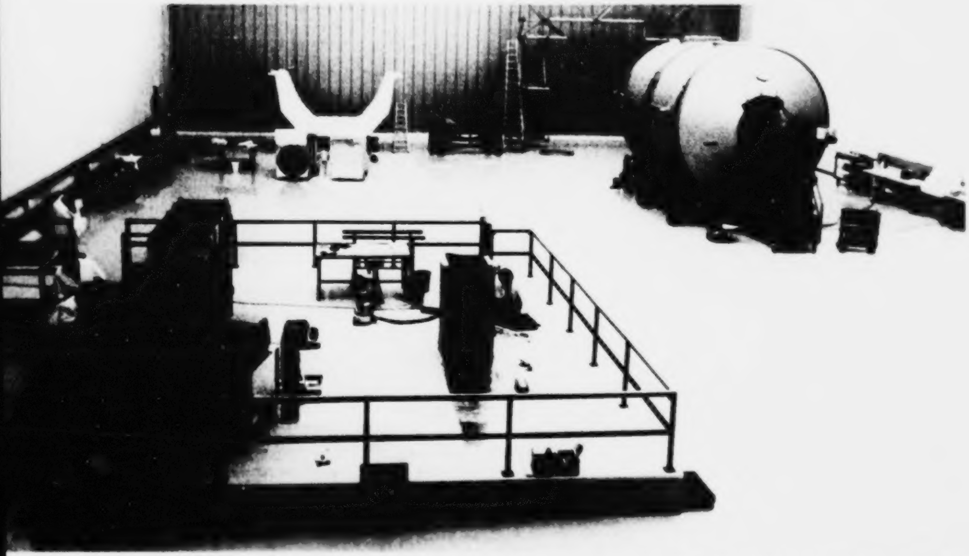


Figure 68. The clean room assembly area in the Integration Hall at ERNO in 1977. Mockups of the Spacelab module and pallet are in the background, and initial equipment for electrical system integration is shown in the foreground.

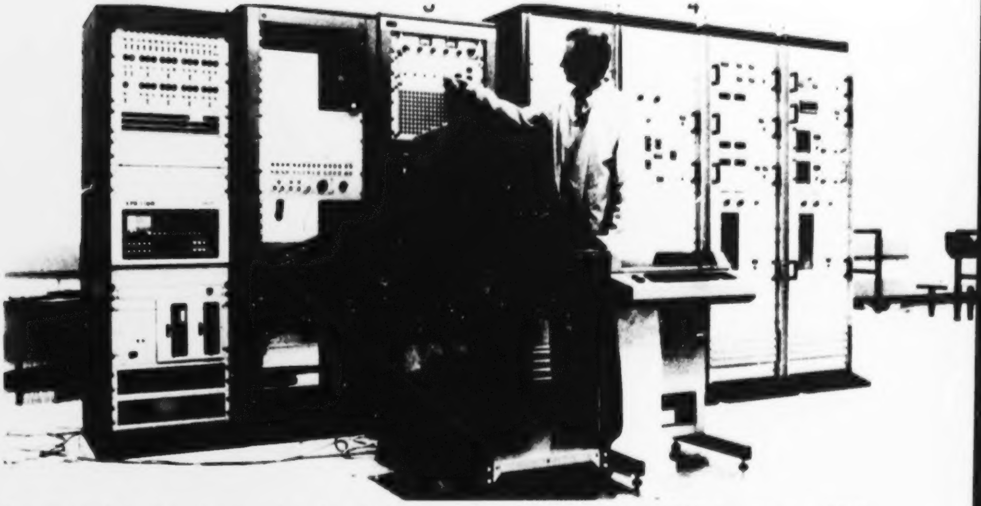


Figure 69. Initial equipment for electrical system integration at the ERNO Integration Hall. Shown from left to right are the interface verification tester (ERNO), the environmental control/life support unit (Dornier), the electrical power and distribution system (AEG), and the ground power unit (BTM).

830—an electrical ground support equipment (set 1) self-test, T 850—electrical system test 1, and T 851—electrical system test 2.

By July 1977 the first ESI activity, the T 800 self-test, had been successfully completed. The objective of this test was to verify the proper installation and functional performance of the electrical power distribution subsystem and electrical harnesses to other ESI subsystems. By the end of September 1977 a similar test (T 810) had been completed on the command and data management subsystem portion of ESI. So far, so good. The two principal breadboards of the onboard electrical and avionics subsystems seemed to work in the ESI installations and verify the performance that had been obtained at the co-contractor sites.

Now all that was needed was successful integration with the electrical ground support equipment from BTM, scheduled to arrive at ERNO on November 1, 1977. Unfortunately, the integration problems now began in earnest. The first area of concern was software. It had been planned that a different set of software would be used for the integration and test program than for later operations. This decision was based on the incompatibility of the test schedule and software readiness dates, particularly in view of the many software changes in process. However, even the test software was not ready. Valiant efforts were made at alternate approaches to overcome schedule slippages, but nothing seemed to satisfy the program needs. An October date for resolution of problems on the integration and test software passed with no solutions in sight before December.

In the meantime, testing that could be accomplished with the breadboards continued. T 820, a subsystem interface compatibility test, was accomplished by early November 1977, and T 840, a compatibility test between the command and data management subsystem and the first set of electrical ground support equipment, newly arrived from BTM, was completed in December. Despite this evidence of progress, by the following April the slippages in checkout schedules were becoming quite serious. The electrical system test (T 850) was completed 3 months behind schedule and all ESI testing had been interrupted for a month to permit another software approach and for refurbishment of the electrical ground support equipment. In order to permit the ERNO team to concentrate on integration and testing of the engineering model, it was decided to cancel the second electrical system test (T 851). Some additional testing and troubleshooting was done with the ESI breadboards but for the most part, ESA Project Manager Pfeiffer reported that ESI testing had been completed by June 1978.

ENGINEERING MODEL INTEGRATION AND TESTING

While electrical system integration testing was under way hardware was arriving at Bremen for assembly of the engineering model (fig. 70). The entire team was looking forward to this phase—at last we would be testing something that really *looked* like a Spacelab. Although the flexibility of the Spacelab design provided for what seemed an endless variety of configurations, it was planned that the engineering model test program would emphasize assembly and checkout of the long module, the long module with an attached pallet, and the short module with three attached pallets. Some initial thought was given to preliminary testing of the igloo with the engineering model, but late decisions on igloo manufacture go-ahead negated this idea. As in the ESI program, the engineering model plan initially included five major test events: T 004—an assembly test involving the racks and floors, T 006—a test of all the subsystems, T 011—an integrated systems test of the long module, T 015—a long module system checkout, and T 008—a short module system checkout. This plan would undergo many modifications during the ensuing months. T 004, the first milestone, was to be completed by February 1978. By April, testing had not yet been started, but was predicted to begin on May 1. Finally, this important milestone was accomplished in June 1978. It included activation, deactivation, and functional tests of the various subsystems. Power-up activities were, in the main, successful, with some difficulties encountered with the command and data management subsystem.

Problems continued to plague the engineering model test program. Late deliveries of hardware and make-work changes became increasingly troublesome. By September, although ERNO could report that the forward end cone, core segment, and experiment segment had been successfully mated in preparation for the module subsystems test T 006 (fig. 71), ESA was forced to admit that the predicted delivery to NASA of the engineering model was 4 months late (now September

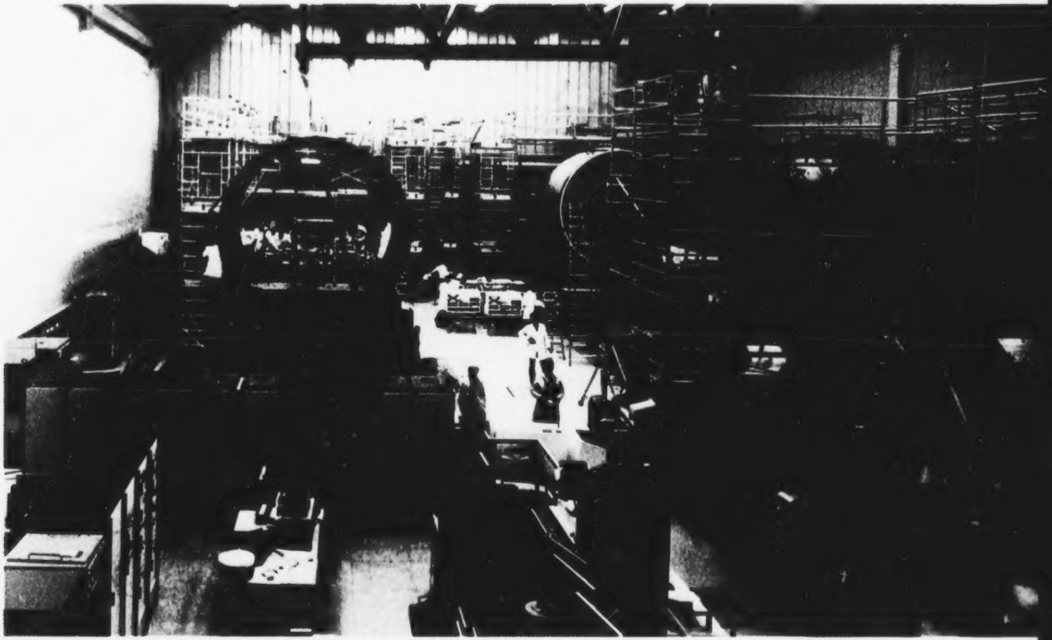


Figure 70. The Spacelab engineering model module and racks being prepared for integration at the ERNO Integration Hall, Bremen, West Germany, 1978. The electrical system integration equipment is shown in the left foreground.

1979). Moreover, although the hardware objectives were achieved, the software was unsatisfactory. In general, the test schedule appeared to be about 6 months late, and significant delays in delivery of flight unit hardware were predicted. Significantly, the November 1978 newsletter from NASA makes little mention of the integration and test activities other than to report on an extensive discussion of hardware and software integration and test activities at the October Spacelab Quarterly Progress Review at ERNO. The integration and test program was in serious trouble. Fortunately (that is, from a Spacelab schedule viewpoint), Shuttle development was also slipping, and with it the need date for Spacelab operational readiness. More serious from ESA's standpoint was the increase in projected cost-to-completion as changes multiplied and schedules slipped.

Despite the continued threat of cost overruns, changes had to be made, even though they would be costly to ESA. One of Bignier's first moves to try to stem the tide of slippages was enlistment of a team of TRW software specialists to bring order and additional management expertise to this element of the program. At the end of 1977 ERNO had asked its old U.S. ally if the European consortium had adequate personnel and organization to manage the software task. A TRW team under Ed

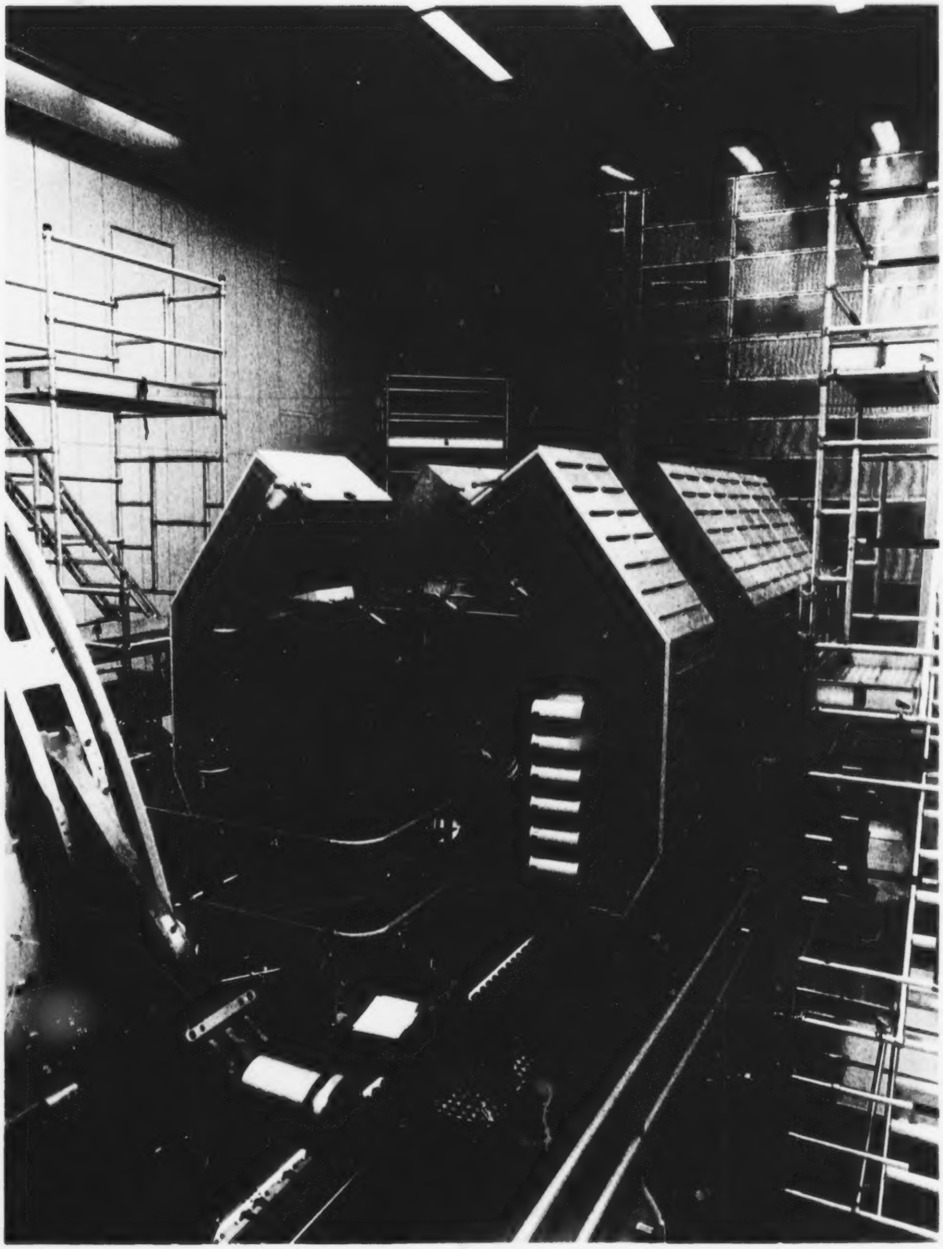


Figure 71. Preparation and installation of subsystems and racks for engineering model test T 006 at ERNO in October 1978.

Goldberg and Dave Barakat audited the program and concluded that, while ERNO possessed the technical skills, it lacked software management capability. A joint TRW/ERNO project office was established to manage the total European software effort for Spacelab. Eleven TRW software managers were assigned to counterparts in the ERNO organization and later ten additional TRW technicians joined the team. The extensive Spacelab software effort, fractionated among many companies across Europe, had to be brought to order and had to provide systems integrity for the software elements. TRW would attempt to train a cadre of capable software management experts within Europe to complete the software development and manage its maintenance. The approach taken by TRW would prove to be remarkably effective. The TRW on-site leader was Howard King, and his counterpart and deputy from ERNO was Wilfried Bark. They worked together hand in glove, as did the other software managers. When the time was right, Bark took over as manager and King became deputy, until it was possible to withdraw TRW support. A similar transition took place with each of the ERNO software managers.

From January 23 to March 10, 1978, an extensive Software Requirements Review was conducted to define the operational software necessary for the Spacelab flight subsystems and the ground checkout computers. This review resulted in a technical agreement among ESA, NASA, and ERNO on the requirements. Four independent software teams (subsystem computer, electrical ground support equipment, system, and support software) generated over 1500 discrepancy notices which were culled to 900, then to 100 for preboard review, and to 37 for final board review. Two of the most important decisions were the agreement that NASA would participate in the ESA/ERNO Software Configuration Control Board and that an onboard checkout interpreter would be deleted.

In addition to creation of the TRW/ERNO software team, ESA decided to abandon the integration and test software and to utilize only operational software in the integration and test program. Although this change caused a hiatus of several months in the test program, once it was in place and working, improvements in schedule were almost immediate. The magnitude and importance of this total turnaround in the software philosophy, especially at such a late point in the program, cannot be overemphasized.

On October 30, 1978, ERNO proposed a new schedule to ESA which forecast delivery of the engineering model to NASA in April 1980 and delivery of the flight unit in two installments: July and November 1980. Although ESA did not accept this proposal immediately, it did recognize these as the best dates for NASA to use in its planning. ERNO had included 6 weeks of contingency time in its proposal, but this would not be the last of the schedule slippages. Meanwhile, NASA itself continued to be overly optimistic about the Shuttle schedule, with the respective launch dates for Spacelab 1 and Spacelab 2 now expected by August 1981 and January/February 1982. The oft-postponed module subsystems test (T 006) was finally completed in January 1979, but by March concern was expressed that T 011 was probably 8 weeks behind schedule. It was often difficult to know what the baseline for these delays was, since by that time there had been so many different schedules.

Although concern mounted about the schedule slips, ESA's principal worry was the escalation of the cost-to-completion. By this time, the previous 120 percent limit was known to be too optimistic and the participating countries would have to be asked to consider a 140 percent limit. ESA Director General Gibson felt this was the absolute maximum that could be obtained; any further increase would cause the death of the program. A further complication to the need for increased funding was that Italy, the second largest contributor to the program at 18 percent, had been getting the short end of the financial return in contracts and was willing to contribute only a token amount to the extra 20 percent needed. The other participants would have to make up the shortfall. Fortunately, a way was found, and the additional funding was provided in time to keep the program on course for its rendezvous with the Shuttle. Before that happened, however, the Spacelab program faced many anxious moments.

Despite the continuing plague of problems and delays, Spacelab managers felt there was nothing seriously wrong with the overall program. Granted, there were numerous small design and interface problems which continued to cause unplanned work and perpetuate delays. However, the basic Spacelab design was considered to be sound. An important management change occurred in August 1979 when ERNO's manager of the integration and test program, Dr. Ekkehard Kottkamp, left for a position with another German industry. His replacement, Jurgen von der Lippe, brought a new sense of direction to the program and a willingness to accept help from throughout the ERNO management structure and from the ESA and NASA resident teams. Procedures which had become bottlenecks in the Integration Hall were simplified to improve program effectiveness. More important, the operational software became available and the test software abandoned. Finally, ERNO made the difficult decision to replace Project Manager Klaus Berge with his very effective deputy, Ants Kutzer. These events seemed to provide catharsis to the program. From this time forward, the program proceeded with a new sense of urgency and confidence.

Throughout this period of final definition, hardware production, and early testing, there were many important contributors within the European team. In addition to those mentioned above, many others deserve special recognition. Within the ESA project team at ESTEC, Wolfgang Nellessen, Otto Steinbronn, Gordon Bolton, and Dieter von Eckardstein provided key leadership and made many of the difficult engineering and schedule decisions. Von Eckardstein later directed the follow-on procurement effort for ESA, after NASA started to place orders for additional flight hardware. Frank Longhurst led ESA studies of operations and logistics and provided important insight to decisions with NASA in this area. Maurice Legg provided leadership in the program control area, which was of particular significance during the adjustment of the program ceilings to 120 and 140 percent.

Within ERNO, in addition to the leadership of Hoffman, Berge, and Kutzer, many others played key roles in Spacelab development: Dr. Wilhelm Boyens and Heinrich Glaeser as Contracts Managers; Peter Gehrke as Co-contractor Manager; Klaus Ziegenbein, Werner Inden, and Hans-Jurgen Pospiezczyk as Engineering

Managers; Ludwig Grimm and Detlev Drewke as Project Control Managers; Jurgen Levold and Rolf Schwenke as Product Assurance Managers; and Dr. Werner Sobotta and Hartmut Bussewitz as Operations Managers. At KAMPSAX in Copenhagen, G. Helmer Nielsen served as the Local Project Manager of software development throughout the life of the program.

MEANWHILE—BEHIND THE SCENES

In 1977 NASA decided to change personnel assignments in Europe. The first change involved the group of technical specialists specifically requested by ESA a year earlier when similar skills had been difficult to find in Europe. Most of the group completed their work and returned to their respective centers. In their place, NASA began staffing what would become a 9-10 person resident team at ERNO to support the integration and test efforts. This test team would act as a "core" team to accept the various hardware elements before shipment to NASA, working closely with their counterparts in the ESA resident team, and augmented by temporary duty assignments of other NASA technical specialists. The team also was to receive on-the-job training for later duties in the U.S. by "hands-on" participation in ERNO's integration and test effort. The position of NASA Senior Advisor at ERNO was terminated. Lowell Zoller, who had filled that role, remained at ERNO to manage the NASA resident team. The first team members to join him in Bremen were Bill Oyler and Eldon Raley from KSC in August and Wallace Jordan, Raymond Lawrence, and Robert Spencer (who later led the team when Zoller returned to the States in 1978) from MSFC in September. Emmett Crooks from KSC was added to the team in January 1978, Gerald Bishop and Thomas Marshall from MSFC in April 1978, and William Wilkinson from MSFC in July 1978.

Luther Powell, who had been extremely effective as Senior Advisor at ESTEC, returned to MSFC to resume his duties as Deputy Program Manager. It was decided that no replacement would be made at this position at ESTEC. However, the Senior Advisor position at ESA Headquarters would be continued and would be filled by Kenny Kleinknecht, the recent replacement for Bob Lindley who had returned to Goddard as Director of Project Management. Finally, Bill Davidson would return to MSFC after 4 years in the Spacelab Liaison Office at ESTEC. His replacement would be Andrew G. (Andy) Kromis from MSFC.

Several more key personnel changes were made during 1978. First, ESA appointed Derek Mullinger, a senior member of the ESTEC staff, formerly with the GEOS-1 project, to replace Max Hauzeur as head of ESA's SPICE organization in Porz-Wahn. Jim Morrison arrived in Paris in March 1978 to replace Pat Murphy as the NASA European Representative. Murphy became NASA's representative at Vandenburg Air Force Base in California to oversee the construction of the Air Force Shuttle launch facilities there. Mel Brooks, the NASA Space Transportation System operations advisor at ESTEC, was reassigned to fill a similar position at SPICE. It was important that those planning the first European payload for Spacelab have the benefit of his operational expertise. These changes were followed by the return to the U.S. of Bill Hamon, the "dean" of the NASA Spacelab liaison team. After 5 years as Senior Liaison Official at ESTEC, Hamon returned to NASA Headquarters as the Chief of Budget in the Space Transportation System Office. His presence in Europe and his many contributions to the ESTEC/ESA/ERNO/NASA liaison would be sorely missed by the entire Spacelab team. Fortunately, Andy Kromis was available to fill Bill's shoes at ESTEC.

Steve Copps, the NASA software specialist on loan to ESTEC, also returned to the U.S. and joined the Martin Marietta Corporation in Denver. Finally, Rudy Selg was appointed as the ESA Spacelab Representative at KSC. The time was approaching when Spacelab hardware would be arriving at the launch site, where Rudy would provide important representation.

HYBRID PALLET CONCEPT

After many discussions and studies of various options, in March 1977 the NASA Administrator decided to proceed with the development of a so-called "hybrid" pallet to be used on several Shuttle orbital flight test (OFT) missions and which would also be available if the Spacelab system was delayed. ESA agreed in part to this idea with a certain amount of reservation. The NASA concept was to utilize Spacelab engineering model pallet structures outfitted with subsystems from other ongoing NASA programs since flight-qualified Spacelab subsystems would not be available in time for the OFT missions. The hybrid pallet would utilize the communications and data handling subsystem being developed by GSFC for the multimission modular spacecraft and a flexible multiplexer-demultiplexer (MDM), cold plates, and coolant pump from the Shuttle program. Thus the hybrid pallet could provide power, cooling, and limited data management support for payloads during the early test flights.

Although ESA recognized the requirement for early payload carriers and agreed that the engineering model pallet structure could be used, it wondered whether "big brother" NASA was taking this approach in order to build a replacement system for the Spacelab pallet-only system. Could ESA trust NASA not to improve on the hybrid pallets and eventually provide as much capability with this system as could be provided by ESA's igloo? As reported earlier, by the time of the October 1977 Director General/Administrator meeting, this point was raised as a key issue, and NASA dropped its idea of using a hybrid pallet as a Spacelab backup. The OFT pallets would be kept very simple, equipped only with an Orbiter freon pump, cold plates, a flexible MDM for command purposes, and a power control box. For its part, ESA was most responsive, and pallets were delivered to NASA in December 1978 and April 1979 for NASA's OFT use.

JOINT SPACELAB WORKING GROUP MEETINGS

The JSLWG ("Jizzlewig") meetings of 1978 and 1979 continued to reflect a plethora of topics and problems. A procedure was adopted whereby each side listed at each meeting what it considered its top 10 problems. It was always interesting to reflect on these lists. Often what one side listed as a major problem, although completely the responsibility of the other participant, was not recognized and listed by the latter. The question of what should be done to resolve each problem listed was also a matter for considerable debate. The high point of these discussions was when agreement was reached that a problem no longer merited top-priority attention. It was like what FBI agents must feel when they finally capture one of their 10 most-wanted criminals.

Obviously the most important items for discussion at every JSLWG meeting were the status items of schedule and cost. However, cost concerns were shared only to a limited degree since each side was responsible for its own funding. It was important to the Europeans to keep abreast of our Shuttle schedule as well, and they never missed an item about the Shuttle which surfaced in the news media or the trade journals, immediately calling us to task if the matter posed any threat to agreed-upon plans. Other items of regular attention at the working group meetings during this period included deliverable items; spares, maintenance, and sustaining engineering; weights; Orbiter/Spacelab interfaces; TV and film requirements; engineering model/flight unit differences; post-delivery change control; European participation in NASA integration; late access to Spacelab before launch; unit testers; and recent hardware/software problems.

One item of particular interest was NASA's decision reported in January 1979 to perform virtually all Spacelab Level IV integration (mounting of experiments to racks or pallets) at KSC. This decision, primarily orchestrated by Tony Calio, then Deputy Associate Administrator for Space Sciences, was the final blow to the early Spacelab concept of decentralized integration. KSC had been successful in its campaign to win sole responsibility for this function on the basis of efficient operation and lowered costs. Although NASA management did not accept KSC's proposal to expand significantly the Operations and Checkout Building for the purpose, the action taken served a death knell to the plans of those at other NASA centers who had envisioned significant hands-on experiment integration activity at their facilities.

PRELIMINARY SELECTION OF FLIGHT CREWS

In August 1978, NASA and ESA announced the first selection of potential crew members for the early Spacelab missions. Drs. Owen K. Garriott and Robert A. R. Parker were named as Mission Specialists for the first Spacelab mission. Garriott, who had been a science astronaut on the second Skylab mission, and Parker, who had played an important role in the ground support of the Skylab missions and who had participated in the Spacelab ASSESS program, were eminently qualified for this assignment. The decision to carry two Mission Specialists represented a breakthrough in principle for JSC management, which still had reservations about Payload Specialists on Shuttle missions and which felt that two Mission Specialists were absolutely essential if two-shift operation was to be considered for round-the-clock Spacelab operations. Early identification of these crew members would help in planning the joint Spacelab payload, even though the mission was not scheduled for another 2 years. For Parker, who had already waited 11 years for a flight assignment, his wait for a mission would prove to take 5 more years.

Meanwhile, both ESA and NASA had been finalizing their plans for the first joint Spacelab payload, and a companion effort had been under way to search for suitable Payload Specialists. On August 8, 1978, ESA and NASA introduced their final candidates for the single Payload Specialist to be provided by each side. ESA had selected Dr. Wubbo Ockels, a Dutch physicist; Dr. Ulf Merbold, a German materials specialist; and Dr. Claude Nicollier, a Swiss astronomer. NASA had selected Byron K. Lichtenberg, a doctoral candidate in bioengineering at MIT; and Dr. Michael Lampton, a physicist at the University of California at Berkeley. This was to be the start of an arduous and lengthy period of training and waiting for these able young candidates.

Shortly thereafter, NASA announced the selection of four solar physicists as final candidates for the two Payload Specialist positions in the Spacelab 2 pallet-only mission: Drs. Diane Prinz and John-David Bartoe from the Naval Research Laboratory, Dr. Loren Acton from the Lockheed Missiles and Space Corporation, and Dr. George Simon from the Air Force Geophysics Laboratory. For these candidates, waiting for the second Spacelab mission would prove to be even more frustrating than for the SL-1 crew.

FOLLOW-ON PROCUREMENT

A continuing series of activities during this period were discussions relating to NASA procurement of a second Spacelab. ESA was anxious to secure for its industrial consortium a guarantee of continued manufacturing responsibilities. Although early NASA planning had sometimes forecast a need for several Spacelab units, it was now clearly evident that only one additional flight unit would be needed for the planned mission model.

As early as November 1976, Spacelab Level II representatives had met at ESTEC to discuss schedules, composition, and cost alternatives for follow-on procurement. Jacques Marchal (ESA) and John Kelly (NASA) provided Level I representation at this meeting, where NASA confirmed that the first increment of procurement would be one Spacelab, with essentially the same composition of pieces as the first flight unit to be delivered to NASA under the ESA/ERNO contract. Two alternative delivery schedules were to be considered: one based on NASA's hardware requirements to meet its mission needs and a second designed to reduce costs by eliminating production gaps.

During the next year, activities continued within the government and industry team to examine various ways to accomplish the above objectives. In general, NASA was looking for ways to delay procurement or reduce costs, whereas ESA and ERNO pushed for an early commitment and minimum production gap. In February 1978, however, the discussions took a different turn when senior NASA and ESA officials met to discuss the trade of one Spacelab for NASA launch services for European Spacelab missions. The results of this meeting were so encouraging that NASA work related solely to contractual procurement was terminated in favor of concentrating on a barter arrangement. A draft Memorandum of Understanding was reviewed by NASA and ESA representatives on March 9, and NASA provided annexes detailing the goods and services to be exchanged on April 3. Hope was expressed that the NASA Administrator and ESA Director General could endorse the concept at their May meeting. Sure enough, at their meeting on May 18, 1978, Frosch and Gibson exchanged letters indicating agreement on a set of guidelines and a timetable leading to signature of the Memorandum of Understanding to formalize the barter by the end of 1978.

Despite the rush toward a barter approach, it was necessary to have a firm evaluation of the cost of the second Spacelab flight unit. Therefore, ESA sent a Request for Proposal to ERNO on May 16, 1978, with a response requested by September 1. A separate request was sent to Dornier for a similar proposal on a second Instrument Pointing System. Both proposals would be required whether the final approach was to be direct procurement by NASA or a barter agreement.

On September 14, a NASA delegation headed by John Yardley and Arnold Frutkin met in Paris with the ESA Spacelab Programme Board to lay out the proposed mechanism for NASA to obtain the second Spacelab flight unit in exchange for Shuttle launch services. Although the ESA group was very cordial, there was a decided chill in the air concerning the proposed barter. At its next meeting on October 25, the board confirmed this impression by expressing its preference for direct procurement by NASA of the second Spacelab flight unit. The formal wording of the rejection of the barter concept was very polite, but beneath the surface were strong European motivations. The entire Spacelab cooperative effort was a voyage into unchartered waters, and some of the European participants were anxious to see whether NASA would keep its part of the bargain, as Europe had been keeping its part, despite the development difficulties. The agreement had specified that NASA would purchase whatever additional units it needed, and these members wanted to see the color of U.S. money. Another concern was whether the ESA requirement for additional Spacelab missions (and therefore Shuttle launch services) was valid. ESA had laid out a very ambitious demonstration program of Spacelab missions, but West Germany had independently proposed to NASA a similar program of Spacelab flights. Would there be enough support in Europe for both experimental programs? In any case, the barter was dead.

Therefore, ESA and NASA turned their efforts back toward direct procurement. ERNO and Dornier submitted their proposals on October 16 and October 27, respectively, and ESA and NASA began their evaluations. A NASA team joined its ESA counterpart in Europe on November 13 with the goal to define a procurement contract as early as possible in 1979.

Almost immediately it was apparent that a new and greater problem had been encountered, as the proposals appeared to be much too costly. The costs for the production units were much higher than anticipated, and in such areas as engineering it appeared that ERNO planned to retain an unreasonable proportion of the development team to support the production effort. New proposals were needed, and NASA again reiterated that it required nothing more than an identical copy of the first unit in this follow-on procurement.

On July 4, 1979, NASA and ESA agreed to a letter contract for the procurement of essential long-lead items necessary for production of a second Spacelab. Included were basic materials such as aluminum and titanium and the work necessary to prepare purchase orders for electric, electronic, and electromechanical (called triple-E) parts. New industrial proposals were now expected on July 31 and a completed contract hoped for in December.

The new proposals appeared to be much more in line, so ESA added its proposed management overhead and submitted its proposal to NASA on September 17, 1979. NASA responded with a list of comments on items to be resolved before negotiations, and the two sides continued to discuss the terms and conditions for an overall contract. It was still targeted to have a go-ahead for ERNO by December; however, the Dornier go-ahead would be held up until completion of its Critical Design Review on the Instrument Pointing System.

Lurking in the background during these negotiations was the question of whether NASA could secure funding from Congress for the proposed schedule of payments to ESA for the follow-on procurement. A unique answer to this question was found when ESA offered to borrow money if necessary to provide funds, and NASA agreed to reimburse ESA with interest when the funds became available. In the President's 1981 budget request to Congress, much of the $150 million requested for Spacelab was to cover the early procurement costs for the second unit. Finally, at the end of January, the contract was signed by Marshall Space Flight Center (as the procurement agent for NASA) and ESA for the purchase of the second unit at a value of approximately $184 million. A very long and anxious series of negotiations had finally borne fruit. On the NASA side, Jerry Richardson, Belton Jones, and Dan Blenis of MSFC and John Kelly and Len Sirota of the Headquarters Program Office deserve special recognition, but the entire team of ESA, NASA, and European industry representatives had moved mountains to complete this breakthrough contract.

AEROSPACE SAFETY ADVISORY PANEL

Recognition needs to be made of the role this important organization made in the Spacelab development effort. Established by Congress after the Apollo 204 fire, the panel performs a safety overview function for all NASA programs, reporting directly to the NASA Administrator and Congress. Howard Nason, the panelist responsible for payload safety items, devoted considerable time to review of Spacelab safety concerns. He was supported by Gilbert Roth of the NASA Headquarters staff. Nason began his review by participating in the CDR activities in Bremen, then reviewed Spacelab payload safety activities at SPICE, and had extensive discussions with ESA Programme Director Bignier. His first observations were that the Spacelab team was a "technically strong and dedicated group of people welding together a program made difficult by geography and different management systems." He was particularly pleased to note that "in spite of resource limitations, when technical compromises are made, safety remains basically untouched." These conclusions were reverified in later visits by panel representatives to ESTEC and ERNO and by attendance at the Quarterly Progress meeting in October 1978 at Bremen. Both NASA and ESA responded quickly and effectively to safety concerns expressed by these competent and unbiased consultants.

IMAGINATORS GROUP

A result of the Director General/Administrator (DG/A) meeting in October 1977, the Imaginators Group was an interesting though unsuccessful attempt to examine future uses of Spacelab and its possible derivatives. The idea was to stretch the imagination of some free thinkers in this regard. ESA and NASA took different approaches to selecting its respective membership. ESA selected Jacques Collet, Bob Pfeiffer, Erik Peytremann, and Dr. Gunther Seibert from within its staff and Professors H. Bondi, G. Puppi, J. Blamont, and Dr. Ludwig Boelkow, a very high-level group of scientists and industrialists. NASA, on the other hand, selected members solely from within its staff: Phil Culbertson, John Disher, Dr. Adrienne Timothy, George Esenwein, Bill Hayes, and Dick Barnes. At the October 1978 DG/A meeting, it was recognized that the group had gotten off to a slow start, but one meeting had already been held and another was scheduled. NASA mentioned that its own supporting studies had received an enthusiastic response from the payload community regarding the possibilities of developing large platform structures. At the February 1980 DG/A meeting, the two agency heads expressed their disappointment on the group's lack of productivity and concurred that it should be disbanded immediately after it completed its report. As near as can be ascertained, no final report was ever submitted by this group and it was permitted to quietly dissolve.

FOLLOW-ON DEVELOPMENT

By contrast with the relatively moribund Imaginators Group, both ESA and NASA conducted a very aggressive effort regarding potential improvements to the

Spacelab system. Initial efforts were chartered by the October 1977 DG/A meeting to coordinate ongoing ESA and NASA studies of Spacelab growth. In support of these studies, the Joint User Requirements Group was reconstituted under the leadership of Dr. Gunther Seibert of ESA and William Goldsby of NASA to review Spacelab's current capabilities from a user standpoint as well as preliminary ideas of the most desirable near-term improvements. This group first met in May and June 1978, concentrating on uses of the Spacelab in its present form mounted within the Shuttle cargo bay. At the next meeting of the Joint Spacelab Working Group on June 12 and 13, the user requirements group made a preliminary report on user needs for more power, heat rejection, energy, data handling, and a smaller and lighter instrument pointing system.

The thrust of the follow-on development studies was to define alternative systems for additional power, extending mission duration, and providing a man-tended free-flying operating mode for users. ESA and NASA had already been planning for possible improvements or additions to the overall Shuttle/Spacelab system. Led by Heinz Stoewer, former ESA Spacelab Project Manager, ESA members had drawn up a plan to present to the ESA Council. Their proposal included improvements in mission duration, electrical power and heat rejection, operational flexibility and payload services, improved command and data management subsystem capabilities, smaller-size pallets than the current concept, and various support structures to mount on the pallet over the tunnel. Out of this effort grew the EURECA concept for an automated free-flying payload carrier to be developed by ESA as a separate program from the Spacelab. The proposal also envisioned mission-dedicated sortie or free-flying Spacelabs and eventual use of Spacelab as a Space Station element.

On the NASA side, advanced study groups investigated means for increasing Shuttle power by use of an extendable solar array or with a 25-kw power module. In fact, in January 1979, NASA Administrator Frosch formally announced that NASA would proceed with both a free-flying 25-kw power module and an Orbiter-attached power extension package (PEP) to provide up to 15 kw for a maximum of 20 days. The power module was to be a system to which the Orbiter and other spacecraft could dock. PEP, on the other hand, would be deployed from the Orbiter to provide power during the sunlit periods of a mission, with the fuel cells supplying the necessary power during the dark portions of the orbit. A deployable test array was eventually carried on a Shuttle mission and successfully deployed in 1984. However, the power module effort, after an enthusiastic start, was subsequently canceled.

Following the meeting between Frosch and Gibson on March 29, 1979, NASA proposed formation of a joint ESA/NASA working group to define the follow-on development program. On June 8, the first meeting of the Follow-on Development Content Working Group was held, co-chaired by Jacques Collet for ESA and Bob Lohman for NASA. The group began work on a charter and a working schedule. They discussed the need to understand the mission model aspects of proposed improvements, including frequency of utilization and inventory requirements, before making recommendations. One of the group's key efforts would be to develop cost/benefit analyses for the proposed improvements. However, by October 1979, the ESA Spacelab Programme Board was indicating its reluctance to approve additional funding for Spacelab improvements in light of cost overruns in the current development program.

Nevertheless, the group continued its work on formulating a jointly recommended program. At meetings in August and November 1979 and February 1980, the group's top-priority recommendations emerged as it considered the options and studied the cost/benefit ratios. The ESA Spacelab Programme Board did relent on its earlier decision so far as to permit ESA to initiate some Phase B studies of the proposed modifications. In September 1980 the group issued its report, which recommended as highest priority extending the mission duration beyond 7 days and increasing power and heat rejection to users by at least 3 kw. ESA agreed to continue Phase B studies of these improvements and NASA would support the effort with inhouse personnel. It would remain to be seen whether anything substantial would come from this valiant effort. Much would depend on NASA's efforts to develop the power extension package or the power module.

INTERNATIONAL SPACELAB SYMPOSIUM

Another first for the program occurred October 10 and 11, 1978, when top journalists and other news media representatives from across Europe attended a 2-day symposium at ERNO sponsored by the West German Minister of Research and Technology, Volker Hauff. The theme of his opening remarks was a strong endorsement of space efforts, Spacelab in particular, and an equally strong challenge to demonstrate the payoff for space activities. Presentations by government and industry representatives provided a broad overview of the status of the Spacelab and Space Transportation System (STS) and an indication of the planning for Spacelab utilization. KSC Director, Lee Scherer, made the STS presentation to a rapt audience as he demonstrated the progress of the Shuttle with movies and slides. Later, during a lively press conference, I was asked many questions concerning NASA's commitment to purchase the second flight unit, the price to be charged for Shuttle missions, and plans for future development of Spacelab.

PROJECT CONTROL ROOMS

These program appurtenances, so prevalent in this era of major space development efforts, also deserve mention. Since everyone felt that without a project control room one could not oversee a development effort of this magnitude, everybody wanted one. Control rooms were built at NASA Headquarters, at MSFC, at ESTEC, and at ERNO. Each had its abundance of charts, pictures, and other graphic displays. Trend charts were analyzed, block diagrams traced, action items listed, organization charts displayed, and schedules scrutinized. A tremendous effort was expended at each location to regularly update and monitor all the material displayed. Teleconferences between these control rooms became the routine mode of operation to minimize travel by management and technical personnel.

The NASA Office of Tracking and Data Acquisition and its Goddard support team, after much debate, permitted the Spacelab program to link its liaison office in the Netherlands by leased land line to NASA's operational communications network (NASCOM) via Madrid. This was very useful to the Spacelab program in keeping abreast of activities at ESTEC, but the link was not too dependable; it was subject to interruption at any time to support NASA operational missions. More important links between the far-flung groups were the Rapifax machines for transmitting documents via telephone connections. When the machines worked, they were an effective means to transfer data and exchange charts. At times, however, it was necessary to resort to telegram (TWX) messages or conventional mail systems. We soon learned to avoid sending mail overseas which did not specify "Air Mail." Sometimes mail was missing for weeks because it had been sent, inadvertently, by sea mail.

Were all the project control rooms and related communications links worthwhile? Certainly, presentations to visitors and regular inhouse status reviews were improved by the availability of program information in central locations. In a program as far-flung as Spacelab, teleconferences, although impersonal and fraught with communications difficulties, became an accepted way of doing business. It seemed impossible, however, to keep the charts current, and the cost to operate these facilities was not negligible. Nevertheless, they were useful to the various managers. Now that the desktop computer era has arrived, with information available on integrated displays at the touch of a button, it is doubtful that such project control centers will again be necessary. Effective communication links, however, are essential to a program as widespread as Spacelab.

Personal Reflections

We found formality of interpersonal relationships within the European team difficult to understand. From the outset, it was obvious that the American custom of quickly adjusting to a first-name basis with coworkers was a strange habit for our European friends to accept. We met workers within the European team who had worked side-by-side for years and still referred to each other by last name only. Sometimes, they did not even know their co-workers' first names. There were members of the European team that I had met many times during the course of the program, and I never learned their first names. In some cases we Americans were unsuccessful in trying to force our informality. In most cases, however, the Europeans readily accepted our friendly overtures and even seemed to like being called Hans, or Klaus, or Francois, or Roberto, or Basil, or Wernher, or even "Pospy" (as in the case of the otherwise unpronounceable Pospiezczyk of the ERNO team).

The extensive travel required by the program lent itself to many unique experiences by members of both the government and industry teams. European travelers to the States could be assured of having a list from their wives of what to bring back from the nearest Sears store. Some of them even developed an affinity for fast-food hamburgers or if not that, certainly a prime rib dinner, unknown in Europe. The ESA and ERNO team members were particularly adept at playing the customs game to its best advantage. When going from country to country they knew which alcoholic product could best be purchased at the duty-free shops. I once witnessed Felix Cabana's embarrassing arrival from INTA at a Bremen hotel when he opened a briefcase upside down only to send smashing to the floor a bottle of Spanish liqueur he was bringing to an ERNO friend. On the other side of the ocean, Hans Hoffmann, the inveterate traveler from ERNO, became a regular visitor to the Jack Daniels distillery not far from Huntsville, and would not rest until he eventually got one of the company's aging casks delivered to his doorstep in Bremen. This was a task beyond the capabilities of any of his NASA or U.S. industry friends, but was finally achieved by a chance acquaintance from Federal Express. What better testimonial to the effectiveness of this organization?

Of course the NASA travelers held their own when it came to taking advantage of their trips. We all became knowledgeable of the relative advantages of Swiss, Dutch, and German chocolates—and our German friends must have thought we were trying to buy every Hummel figurine in the country. The greatest advantage of European travel, however, had to be when we managed to add a few days for leisurely sightseeing, skiing, looking up our European "roots," or otherwise enjoying the wonders of the continent. Despite the concerns of Congress and GAO about government-funded "boondoggles," we found that by careful planning and by paying for additional personal expenses, we could in good conscience enjoy the extra opportunities afforded by these trips. On the other hand, there is no way to measure the financial cost and personal strain on the individuals (and their families) who had to make many of these trips. Traveling on the weekends and at night to be ready for weekday meetings, working weekends and holidays, extensive separations from homes, missed connections, canceled flights, to say nothing of the insidious effects of jet lag, are just some of the problems we encountered.

One trip during this period that stands out in my memory was in December 1976 at the conclusion of the Preliminary Design Review. Except for some unusual problems near the end of the week, this was a typical European trip for me. After leaving Washington on Thursday night, Friday and Saturday were spent in PDR meetings at ERNO in Bremen. Sunday we flew to Milan, then were driven to Turin by the Aeritalia people. Monday was spent in meetings with Aeritalia and flying to Paris. Tuesday was spent in meetings at ESA Headquarters and flying back to Bremen. Wednesday a special summary of the PDR was presented to the ESA Director General, after which we flew to Amsterdam. On Thursday we drove to Antwerp to review progress at BTM on the electrical ground support equipment. Just 8 months after my open-heart surgery, I was having excruciating lower back pains and managed to get some relief only by lying down in the back seat during the drive to Antwerp with Bill Hamon, our NASA liaison man, and Jacques Marchal of ESA. Somehow I was able to survive the very intense day at BTM and the flight home the next day. Within a month, however, I was once again under the surgeon's knife, this time to have a disc removed. Fortunately, my deputy Jim Harrington was able to step in and perform my managerial duties without the program missing a beat.

Many of us tried to predict whether the equipment coming from various countries would have some of the characteristic attributes of the contributing country. For example, would the mechanical ground support equipment look like the Spanish cannon carriage we had seen being pushed over the mountains in the movie "The Pride and the Passion"? Would the wheels have beautifully hand-carved spokes? We were in fact quite ignorant about the technical capabilities of many of our European partners and were pleasantly surprised when we were able to view firsthand the products of their innovative designs. Watching the MGSE perform in the Spacelab assembly process was to observe the product of a first-class technical team.

In development of the electrical ground support equipment, we were continuously bombarded from within NASA by proposals to substitute the launch processing system (LPS) equipment being developed to check out the Shuttle. LPS would reduce the number of people necessary to conduct a Shuttle launch countdown at KSC by at least an order of magnitude from what it had been in the Apollo Saturn launches, so it was truly a revolution in the state of the art. Nevertheless, NASA advocates of this change were ignoring the importance to Europe of developing its own capabilities in this area and the additional cost to NASA if the change were made.

There were many interesting aspects of working with the Italian team at Aeritalia. In one of the first meetings when the ERNO prime contractor representatives were in Turin, an attempt was made to expedite the day's activities by having a working lunch. Professor Vallerani, the Aeritalia team leader, had been busily at work on the sidelines setting up a typical 3-hour Italian lunch. When faced with the unheard-of proposal that sandwiches be brought in, his first reaction was one of shock, then dismay, and finally disbelief. He noted several times it *could* be done, it would just take *one* phone call, was that *really* what we wanted to do? After several reiterations of the request and of his response that it *could* be done, he finally exploded with: "Yes, it can be done—but it's never *been* done!" With that, the visitors gave up and accepted plans for a more modest lunch than usual—only five courses!

Our first visits to Aeritalia were eye-openers. In many respects the manufacturing facilities had all the attributes of a boiler factory, an old one at that. But on closer inspection we observed modern, numerically controlled milling machines and technicians who could compare with the best in the U.S. Although by U.S. standards their production safety standards appeared to be lax, the technical team could and did turn out precision products. On the other hand, in at least one area, the lack of precision has hurt the program. From the beginning, Spacelab was planned to provide standard interchangeable 19-inch aircraft racks for mounting electronic and experiment equipment. Somehow, despite this requirement, the actual racks are each slightly different. Whether the manufacturing jigs were of insufficient tolerance, whether the basic design was faulty, or whether inspection and post-manufacturing handling procedures caused deformations has never been answered to my satisfaction. Those who hold basic design at fault point to the weight-saving campaign at the start of the development phase of the program and believe that Aeritalia went too far in reducing weight so that the racks distort very easily. In handling the integration of equipment in the racks in the early missions, each rack had to be handled as a unique structure. This is obviously detrimental to efficient use of the system. It is hoped that the problem has been solved by a combination of slotted holes and reinforcement of the structures.

Working with the English, or British, or United Kingdom team (we were never quite sure which name to use) was quite different from working with the Italians. First of all, their use of the English language was usually so impeccable that they put us Americans to shame. Second, their analytical capabilities and materials knowledge were extraordinary. Of course the British tea breaks were as necessary and predictable as the expresso breaks at ESA Headquarters. And the British were the only Europeans who could relate to my passion for golf. Although I never had a chance to try one of their "links," we had many fine discussions about them. On one trip to the Hawker-Siddeley facility at Stevenage, while awaiting John Yardley to recover from a Sunday arrival in Europe, Bob Lindley and I visited nearby historic Knebworth House, which I could understand and enjoy, and a cricket match, which was completely baffling and seemingly endless.

Dornier System was an unusual corporation within the Spacelab family. Perched in an idyllic setting on the shore of Lake Constance, it gave a continual reminder of its rich aeronautical heritage, harking back to the early dirigibles and the Dornier flying boats. Alone among the West German aerospace industries, the company has been able to retain its private industry character and managerial link to the Dornier family, although some of the family seams were beginning to tear apart in recent years (it has since been taken over by Daimler). In any event, with the area's beautiful scenery, its moderating lake breezes, its delicious cuisine featuring lake trout and salmon, and its wonderful local wines, Dornier was a popular stop on the Spacelab itinerary, despite the sometimes hectic rides by ferry and car to and from the fog-shrouded Zurich airport, the nearest large airline terminal.

I recall with amusement an early trip to Dornier when a demonstration was given of the fire suppression system for the Spacelab racks. A mockup of the racks had been built and each rack had windows with small kerosene lanterns hanging within. When the fire suppression system was triggered, of course, the lantern flames were snuffed out. Although this was an effective illustration that the system worked, it seemed primitive in view of the high-technology field in which we were engaged. One would have expected a battery of sensors, gauges, strip-chart recorders, and the like to confirm the distribution and concentration of fire suppressant to the desired volumes of the racks.

The use of European rather than U.S. electronics in the command and data management subsystem was and still is perhaps the most difficult pill for American engineers and industry to swallow. This has been greatly aggravated by the continuing and rapid advancement in the state of the art. Equipment selections were 10 to 12 years old by the time of flight and even when chosen were generally regarded as proven state of the art. Only two components used relatively advanced technology, the high-data-rate recorder, which, with its precision tape transport unit, is an American product, and the high-rate multiplexer, which also is based on U.S. technology. On the other hand, the data display unit is French and based on excellent aircraft experience. The central computer is also French with both land-based and marine military origins. The computer, at the time of its selection, was comparable to the IBM 101 unit selected for the Shuttle general purpose computer. Today, many view both systems as obsolete.

I found that visits to MATRA in Velizy, near Paris, to review progress on the data system, although interesting, were never completely satisfying because of my limited knowledge of electronics and my subsequent lack of appreciation for the endless black boxes and racks of electronic gear. Of course I could not help but be amazed at the revolution under way in electronics as new techniques miniaturized the size of every component and as printed circuit boards and silicon chips became increasingly more capable. The MATRA plant was also an ultra-modern example of General DeGaulle's determination to have high-tech industry to support the French military. Sometimes I took more enjoyment from my encounters with the flamboyant managers of the MATRA team, particularly Noel Mignot, the overall boss, who delighted in terrifying visitors as he drove us to lunch in his MATRA-built sports car at Grand Prix speeds!

AEG, located in Hamburg only an hour's drive from ERNO in Bremen, would seem to have been a logical place for NASA visitors to stop off in Europe. We often landed in Hamburg from other countries. That AEG did not receive a significant number of visitors is indicative of the relatively small number of development problems there. Those who did happen to visit there enjoyed the beautiful downtown lakes and extensive rhododendron gardens. They were also intrigued by the extensive entertainment area with its city-licensed Eros centers. This was definitely not Hometown, USA!

Almost every European industry in the Spacelab program was also involved in the European aircraft industry. As we traveled, we often glimpsed activities on European aircraft such as the MRCA and the Airbus, various national programs, or activities in support of NATO programs like the F-104 and the F-16. I sometimes wondered why NASA ever questioned Europe's technical capabilities to develop manned space systems. Certainly space development was not that far removed from advanced aircraft development.

Although some NASA visitors found their way to SABCA, Fokker, SENER, and KAMPSAX, in addition to the co-contractors already mentioned, most of our trips were to ERNO in Bremen (fig. 72). This charming city, which with its sister harbor city of Bremerhaven constitutes a politically strong state within the Federal Republic of Germany, possesses a rich heritage and friendly ambiance which we greatly enjoyed. The market place with its surrounding buildings, the ornate Rathaus (city hall), the Dom (cathedral) dating from the year 1000, the Guild Hall, and the contrasting modern Parliament Building, is the center of many activities. The nearby old fishermen's village known as the Schnoor, with its narrow alleys and tiny buildings, provides a quaint area of shops and restaurants. The Boettcherstrasse is a unique walking street of unusual architecture which includes a beautiful glockenspiel mounted on the roof of a building and what at first appears to be a brick turret of the building that rotates, as the glockenspiel is being played, to display colorful panels of Bremen historical occasions. Excursion trips on the Weser River, shopping in the modern stores, or visiting the museums are just some of the attractions offered by this rejuvenated city, almost completely leveled during World War II. On one early visit the ESA and NASA operations team showed their unity by purchasing and wearing the traditional Bremen boatman's cap, the *Wesermutze*.

The ERNO facility itself, somewhat overshadowed at the start of the Spacelab program by its parent VFW facility on the same site, is located at the edge of the Bremen airport and captive to the noise of landings and takeoffs. That did not seem to deter the sizable wild rabbit population that resided in the open courtyard of the ERNO office building, playing havoc with the efforts of the landscaping crew. In addition to viewing construction of the Spacelab Integration Hall during our visits, we observed the construction of a vertical assembly facility for assembly of the second stage of the Ariane launch vehicle. ERNO has now added a very impressive facility on the other side of the airport for the horizontal assembly of liquid boosters for the advanced Ariane vehicles.

Figure 72. Left to right, Luther Powell, John Thomas, and Jack Lee, key members of NASA's Marshall Space Flight Center Spacelab team, arrive by trolley at the ERNO facility in Bremen for a day of meetings.

From the outset, ERNO reflected a different organizational setup than we were accustomed to. The ERNO management structure was a vertical arrangement in which information flowed freely up and down the chain of command but had difficulty crossing interdepartmental boundaries. The engineering team was completely isolated from the operations group and each was similarly separated from the test department. Until opportunity was provided for cross-talk between departments, management problems persisted. Each department operated as an independent empire.

Looking back on the Spacelab electrical system integration (ESI) tests, one could question the necessity of that entire operation. However, in the case of the Space Shuttle program, a complete laboratory was developed at Houston for similar purposes, known as the Shuttle Avionics Interface Laboratory (SAIL). Granted, the Shuttle is far more complicated than the Spacelab, but it is still doubtful whether the Spacelab engineering model and flight unit testing would have been as successful as it was without testing the prototype hardware and integration and test software in the ESI. Problems in both hardware and software systems were uncovered early in the testing, as difficult as the testing may have seemed at the time.

In resolving the software problems, one additional contributor should be recognized. Dolf Thiel was the TRW Vice President who made the critical decision to help rescue ERNO in this area. He knew there would be little reward for TRW if the team were successful and much criticism if it failed. Nevertheless, he took the gamble and obtained top software managers and technicians for the program when such talent was a very scarce commodity, much in demand by other elements of TRW. Dolf was almost fanatical in his desire to assure that this effort succeed and in keeping all parties fully aware of the team's progress. It is a tribute to his skill and dedication not only that the software worked, but also that ERNO developed a significant software management capability.

Once the NASA resident team began arriving at ERNO, we assumed that the flow of information on integration and test activities would be greatly improved. It was, but there were many problems. ERNO resented ESA and (particularly) NASA onlookers in the Integration Hall and did not make life easy for them. ERNO once stated that there was no reason for NASA representatives to attend the daily schedule meetings because most of the dialogue was in German. Of course the fact that ESA Resident Manager Alan Thirkettle, who spoke no German, was attending tipped their hand to the contrary. In any case, the NASA team called the bluff and said they would be happy to send a representative even if the meetings were in German. Nevertheless, the NASA team found it difficult to keep current on the planned testing and to obtain access to the Integration Hall when important tests were under way. Perhaps the NASA team was its own worst enemy because its reports back to Washington and Huntsville usually concentrated on the problems it encountered, thus implying that everything was negative. Also, in some cases, there were personality conflicts within the team, with ESA counterparts, or with individuals on the ERNO team. Eventually, however, the problems were resolved. Personnel changes, where necessary, were made. As the groups worked together, mutual respect developed. Most important, as the test program progressed, suspicions lessened and cooperation improved. ERNO, ESA, and NASA test personnel finally began to work together as a team.

8 Off The Mainstream
1974-1984

The central effort in the Spacelab program was to define and develop the module and pallets, to provide suitable interfaces with the Orbiter and the payloads, and to demonstrate that the system was ready to fly. In this chapter we address some peripheral hardware and topics, which, although not primary, were nonetheless essential to accomplishing overall program objectives.

INSTRUMENT POINTING SYSTEM

No portion of the Spacelab program was more challenging in terms of technical complexity, organizational responsibilities, schedule difficulties, and cost escalation than the Instrument Pointing System (IPS). A book could be written about this aspect of the program alone. Chapter 3 noted that in mid-1974, when ERNO was selected as Spacelab prime contractor by the ESA Tender Evaluation Board, it was decided to postpone a commitment on the pointing system. Instead, a 9-month definition study was to be performed by ERNO's co-contractor, Dornier System, assisted by MBB. It was clear that the German government was pressing hard for MBB to receive a substantial share of the contract effort in this regard as partial compensation for its losing the prime contractor competition.

By November 1974 it was apparent that the Dornier team was leaning strongly toward a design characterized as an "inside-out" concept. Most previous concepts for pointing systems employed a yoke circling the instrument to be pointed at its center of gravity. The early design requirements for the Spacelab IPS called for a three-axis system with ±1 arc-second pointing accuracy, capable of positioning an instrument weighing up to 2000 kg with a diameter of up to 2 meters and length up to 4 meters. The size and weight of the yoke mount for such a large device caused the design team to propose an end-mounted approach in which the three gimbal systems would be mounted on the pallet providing support to a circular mounting frame to which the optical instrument(s) would be attached (fig. 73). Because the IPS would be operated only in zero gravity, the gimbal support structure could be built to handle only the momentum of the instrument masses; during launch and landing the two assemblies would be disconnected from each other and clamped to the pallet structure for support. Although this approach would pose difficult problems in ground testing and mission simulations, it would provide a relatively lightweight pointing system. Heinz Stoewer, ESRO Project Manager, gave the IPS project team, led by Dr. Colin Jones and Helmut Heusmann, preliminary authorization to proceed with this imaginative concept, with final authorization to be given by December. In the meantime, NASA invited ESRO to attend its IPS technology conference at the Goddard Space Flight Center on November 21.

At the June 1975 meeting of the ESA Director General and the NASA Administrator, a review was presented of the status of the IPS proposal. The agency heads agreed that ESA would evaluate the increased cost required to improve the performance specifications and the planned test program. (NASA had expressed its concerns about shortcomings in both areas.) The Joint User Requirements Group was asked to reevaluate the system performance values which would be satisfactory to potential users. Although MSFC had issued an IPS Requirements Document in August 1974 and "An Assessment of the IPS for Spacelab Missions" the following November, it was evident that it was very difficult to get designers and users to agree on a statement of specifications. In actuality, a satisfactory set of design requirements was never agreed to by the two agencies and imposed on the contractor. For example, neither the minimum structural frequencies nor the time periods for which performance parameters had to be met were specified.

At the July 1975 Joint Spacelab Working Group meeting, ESA's Wolfgang Nellessen reported on the status of the IPS, including preliminary evaluation of a proposal from Dornier received July 15. He expressed the opinion that the stability and accuracy of the system would be better than the official performance characteristics, but this could not be proven under 1 g conditions. Gerry Sharp reported that the IPS would meet most of the performance requirements of the major instruments under consideration by NASA.

By late August, ESA Programme Director Deloffre reported to NASA that simulations were under way at both Dornier and Marshall to confirm system performance. ESA was proposing to hold the contractor to less stringent specifications than the design goals in order to reduce program costs, but anticipated that eventual performance would approach the goals. Deloffre projected an approval of contract go-ahead by Director General Gibson in September. Deloffre also expressed his concerns about NASA's development of a parallel system for instrument pointing. Goddard's proposed Small Instrument Pointing System (SIPS), an outgrowth of a star tracker gimbal system, had been brought to his attention. This was the first of many concerns to surface.

By my September meeting with Deloffre, plans for a go-ahead had fallen apart. ESA had rejected the Dornier proposal (submitted through ERNO as the prime contractor) because of unacceptable schedule and cost risks. ESA then issued a new Request for Proposals to ERNO, MBB, and Dornier, with responses due December 5. By early 1976, two proposals had been received, a joint bid on the IPS by Dornier and MBB, and a bid from ERNO covering integration of the IPS into the Spacelab. ESA again asked NASA to assist in evaluating the proposals. Although I agreed to provide such support in a memo to Deloffre on January 8, 1976, I expressed major concerns about the delays in the decision-making process on the IPS and the continuing performance deficiencies. NASA was particularly concerned about the free drift mode for stellar pointing, the suitability of the IPS for Earth observations, and cryogenic instrument cooling.

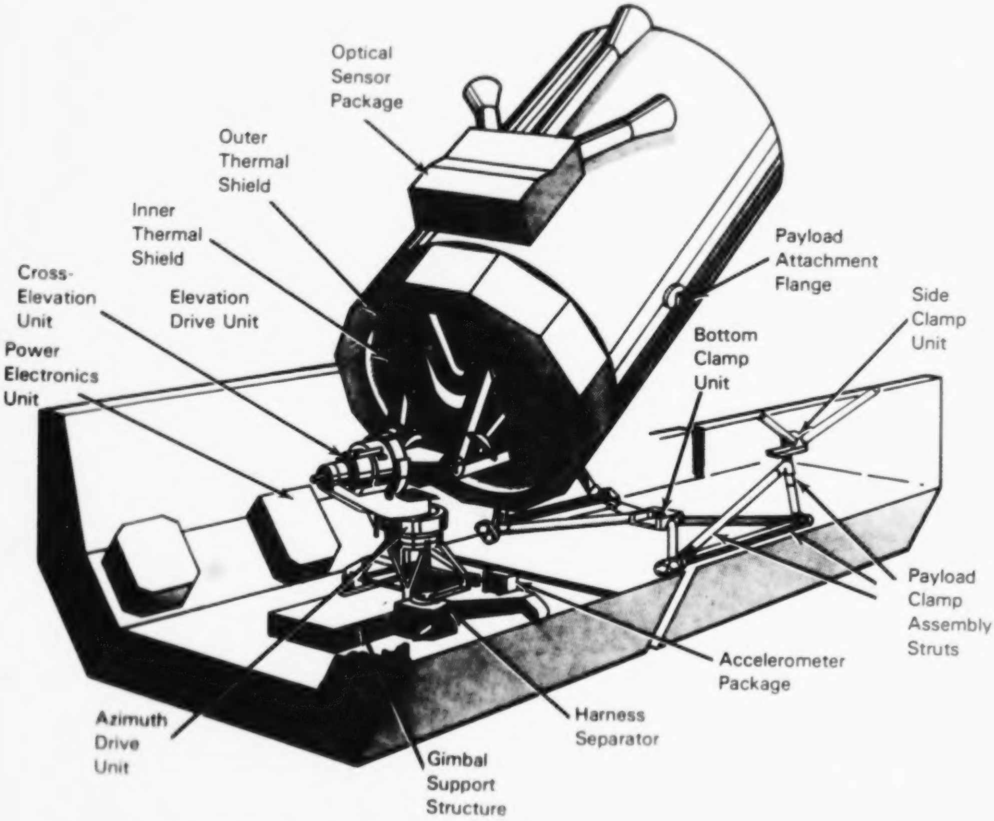

Optical Sensor Package
Outer Thermal Shield
Inner Thermal Shield
Cross-Elevation Unit
Elevation Drive Unit
Power Electronics Unit
Payload Attachment Flange
Side Clamp Unit
Bottom Clamp Unit
Payload Clamp Assembly Struts
Accelerometer Package
Harness Separator
Azimuth Drive Unit
Gimbal Support Structure

Figure 73. Dornier's initial design of the Instrument Pointing System showing the end-mounted system and payload clamp assembly.

Colin Jones, ESA IPS Project Manager, and Dr. Jan Burger, Stoewer's science advisor, continued to work with the Marshall payload teams, trying to convince them that the proposal was satisfactory. By March, the ESA Industrial Policy Committee authorized Deloffre to proceed with the IPS contracts. NASA still had reservations about its Earth-pointing capability and warned ESA it might require the development of its own pointing system for small instruments. On March 17, 1976, the NASA hierarchy, including Fletcher, Low, Naugle, Mathews, Yardley, McConnell, Calio, Culbertson, Frutkin, and myself, met to deliberate the latest ESA proposal. We agreed to advise ESA that NASA would use an ESA IPS that met the specification requirements and that our first potential use would be on the Spacelab 2 missions. Finally, on June 16, Fletcher signed a landmark letter to Gibson concurring with ESA's plans to proceed with IPS development. Fletcher urged that the delivery schedule provide adequate time for integration of payloads and checkout of the combined system for the planned launch date late in 1980. How optimistic this turned out to be.

In any case Dornier was off and running, with MBB to some degree the tail wagging the dog. Although a subcontractor to Dornier, MBB had been given a larger share of the contract (60 percent) and principal fabrication responsibility. The target schedule called for delivery of the flight unit by April 1980. A unique approach was taken in that there was to be no dedicated prototype, or engineering model. In some instances, hardware elements would be used for the test program and retained as a part of the flight unit. And the ESA Spacelab project team, its hands full with Spacelab development problems, left Jones and Heusmann to themselves in managing the IPS effort. These three decisions would later be questioned.

Already by September 1976 some expressed thoughts about a need to decouple delivery of the gimbal system from the clamp system, since delivery of the total system by April 1980 appeared unlikely. In the meantime, JPL had done a study of experiment pointing mounts, which added new fuel to the fire about NASA centers competing with the IPS. Nevertheless, another obstacle was overcome when the ESA Spacelab Programme Board met on March 16, 1977 and decided not to cancel IPS as part of the overall program descoping. An interim design review had been conducted at ESTEC and Dornier with Marshall participants, and the review revealed what was considered to be a sound and mature system design. A delivery slip, however, was forecast as inevitable. Then, on June 16, ESA signed a fixed-price contract with Dornier for development of the IPS with a delivery date of June 18, 1980. As part of its contract, Dornier would be solely responsible for management of the IPS/Spacelab interface—there would be no subcontract for this function to ERNO. The fixed-price feature would turn out to be another mistake in the initial series of decisions on the IPS.

The IPS Preliminary Design Review was held in December 1977. Concurrent reviews were held at MSFC and ESTEC; the final phase was held at Dornier. Results were encouraging except for two discrepancies: certain structural elements were found to be made of materials susceptible to stress corrosion and IPS software requirements needed better definition. During the next year actions were taken to resolve both issues. The materials for several components were changed and an aggressive effort was undertaken to define the required software. It was obvious that the IPS would place difficult software requirements on the Spacelab data system. Special study efforts were also undertaken to understand the thermal environment for the IPS and to define the attitude constraints to be imposed on IPS users.

The technical challenge facing the IPS team was formidable. It was soon realized that specification of a pointing accuracy of ±1 arc-second was only the tip of the iceberg. It was also necessary to define pointing accuracy, quiescent stability, disturbance error, and stability rate, all in both line-of-sight and roll directions. In terms of hardware assemblies, the following would be needed: three bearing/drive units (to move and stop the pointing system about its three axes) payload/gimbal separation mechanism (to off-load the payload weight during ascent and descent), replaceable extension column (to place the pointing system at the proper vertical position in the cargo bay), support structure and rails (for mounting the pointing system to the pallet), optical sensor package (to provide pointing reference to known stars and the Sun), payload clamp assembly (to carry the payload weight during ascent and descent), and thermal control system (to provide temperature control). Power had to be provided to the drive units and across the gimbal system to the payload. Similar provision was necessary to carry data from the payload across the gimbal system to the Spacelab data system. The drive mechanisms were extremely complicated devices consisting of DC torquers, resolvers, main and auxiliary shafts, a load bypass mechanism, ball bearings, and provisions for passing heavy power cables and a large number of signal wires through the drive assemblies to the experiments. The drive systems had to provide for a reasonable rate of slewing but with accurate braking to secure the desired pointing and stability precision (fig. 74).

By January 1979, Colin Jones was able to present a detailed progress review of the IPS to the Joint Spacelab Working Group. The delivery to KSC was now projected for July 1981, which did not quite match NASA's April 1981 need date, 9 months before the scheduled launch of Spacelab 2. Jones reported that current IPS performance predictions were in line with contractual requirements except for the man-motion disturbance in which simulations assumed an astronaut pushing off the wall of the Orbiter or Spacelab. It was agreed to relax this requirement from 3 to 4 arc-seconds. Jones also reported that the IPS software requirements exceeded the Spacelab core allocation for computer memory. Arguments ensued about NASA's requirements for IPS documentation and ESA's concern about NASA's competitive development of pointing systems. In addition to the Small Instrument Pointing System under consideration at Goddard, two other developments had been uncovered by ESA: the Annular Suspension Pointing System (ASPS), a low funding level technology effort supported by Langley to provide a magnetic suspension vernier pointing system (0.01 arc-second), and the ASPS Gimbal System (AGS), a two-axis gimbal system to provide coarse pointing (1 arc-second) for the ASPS. The AGS was under development at Sperry funded by the NASA Office of Space Sciences. Except for the fact that AGS was a two-axis system, it appeared to be a direct competitor with the IPS. Fortunately, NASA eventually recognized this fact (and its escalating development costs) and canceled the AGS program.

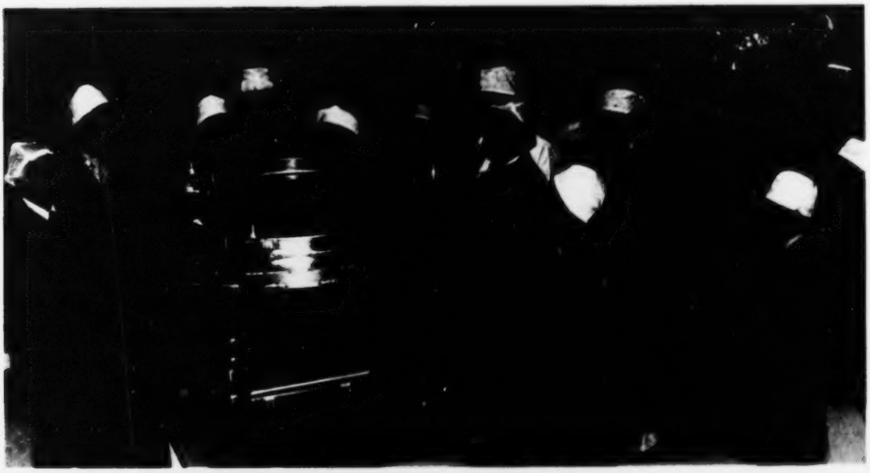


Figure 74. Spacelab program officials view early development hardware for the Instrument Pointing System at the MBB facility in Munich, West Germany, February 1978.

Bignier and I attended the March 12, 1979 program review at Dornier and observed progress in the assembly and testing of all major hardware elements. The key problems were a 2-month delay in the drive assembly due to a clutch problem, disagreement on some testing, provision of a finite element model for stability analysis, and inability of Spacelab software to operate on Dornier equipment. All sides expressed strong feelings at this review. Dornier was upset with ESA because it was unwilling to pay for much of the "make-work" activities (remember the fixed-price commitment). Dornier and ESA were angry with NASA because it appeared to be reneging on its obligation to order a second IPS. For its part, NASA was concerned with IPS development problems and with the questionable delivery of the IPS in time for the Spacelab 2 mission. NASA was also wondering about the advisability of committing to purchase a pointing system which could not be proven except in flight and for which NASA projected few mission plans. Many NASA and ESA personnel were concerned about the lack of an in-depth design review and the inadequacy of the analyses and tests being conducted. Colin Jones seemed to ignore or dismiss most questions and pressed forward, following Stoewer's instructions to "design to cost." There was growing evidence that the performance of the system would be unacceptable.

In any event, Dornier went on with IPS development. In June and July 1979 a System Compatibility Review was held to verify the IPS design qualification on the basis of the testing already performed. The NASA team reviewed the test reports at MSFC and then participated in joint reviews with the ESA team at ESTEC and Dornier. Several hardware problems surfaced, the most serious of which related to the structural failure of the load bypass mechanism and the ability of image dissector tubes in the optical sensor package to survive the Shuttle launch environment.

Although IPS development seemed to be making some progress, technical and management problems continued to multiply. Questions were raised about the ability to operate two IPSs on a single mission. (This may have been a smoke screen raised by supporters of the competitive NASA system since it did not depend on the single Spacelab subsystem computer which one IPS uses to capacity.) ESA questioned whether users could accept a 6 arc-second disturbance response error. Concerns were expressed about the structural flexibility of the IPS drive system (it was sometimes stated that the IPS had the rigidity of a wet noodle). ESA, anxious to secure NASA's commitment to purchase a second unit, agreed to a two-stage Critical Design Review to provide early information required by NASA before making such a commitment. The first phase, CDR-A, was held in February–March 1980. Unfortunately, an IPS drive unit failed for the second time while the review was under way. Nevertheless, CDR-A was completed on schedule with certain performance, safety, and software shortcomings identified. More importantly, NASA reluctantly agreed not to insist on redesign of the drive unit to increase system stiffness. NASA also gave ESA a list of 10 IPS technical design problems it considered significant.

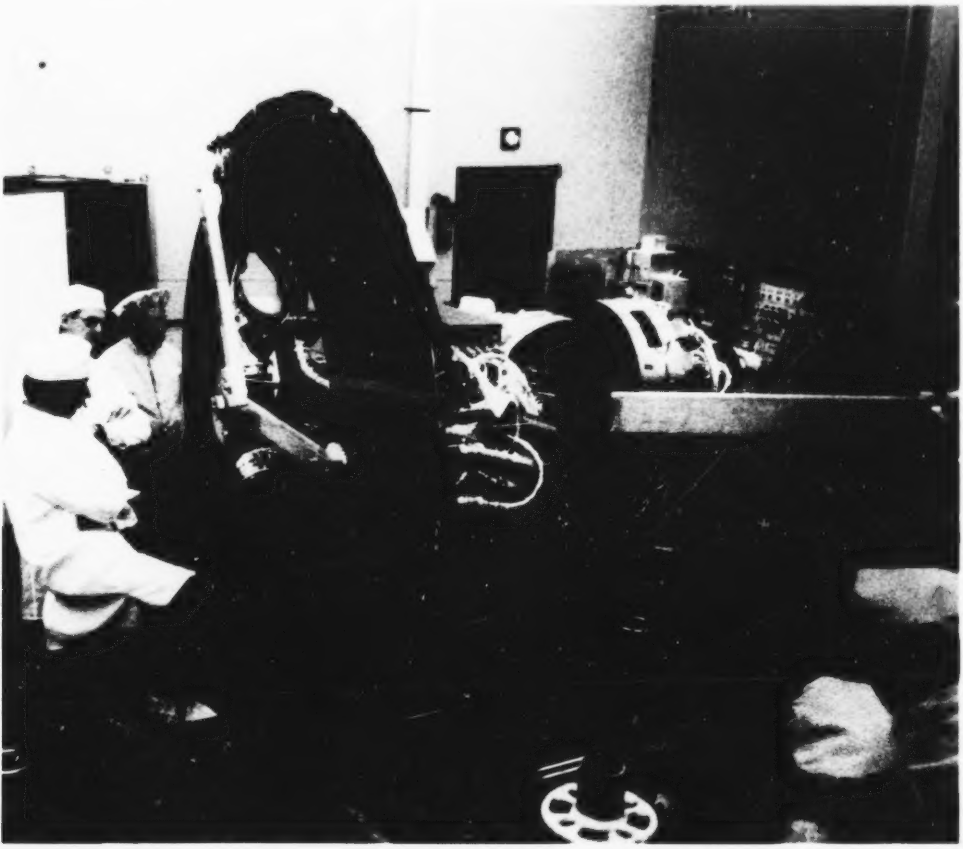
As if to confirm NASA's confidence in ESA and Dornier to solve the remaining problems on IPS, an ESA/NASA agreement was signed in late May 1980 for procurement of a second IPS for approximately $20 million, scheduled for delivery in the fourth quarter of 1983. It was recognized that serious problems still existed in achieving the specified performance, particularly the requirements for quiescent stability and man-motion disturbance response error, as indicated by recent NASA simulation results obtained at MSFC by Gene Compton and Harvey Shelton. In the meantime, an important management change occurred in April 1980 when ESA Project Manager Colin Jones left the program and was replaced by Peter Wolf, who had headed the ESA Resident Office at ERNO during the critical period of electrical system integration and engineering model testing. Dr. Jones had applied for another position within ESTEC the preceding year and had delayed his departure from the IPS project at the request of ESA Spacelab management.

Wolf was in for a shock. The more he and his augmented team investigated the program, the more he became convinced that the difficulties of IPS development had been grossly underestimated. NASA continued to bombard him with increased loads inputs from the Shuttle/Spacelab coupled loads analyses and with recommendations for improvements or redesign. A technical redesign of the drive unit proposed by MBB was rejected by ESA as inadequate for the newly increased loads. By July 1980, Wolf had identified 29 major problems within the IPS development effort—and the final Shuttle loads had not yet been received from NASA. Among other problems, new safety concerns had been uncovered by a NASA safety system assessment. Wolf's conservative estimate of the cost to solve all the problems was an increase in program costs of approximately 35 percent.

Nevertheless, there was still hope for the program. At the next Quarterly Progress Meeting at Dornier on October 31, 1980, Dornier gave an optimistic review to

Bignier and me and demonstrated the slewing and pointing capability of the assembled system (fig. 75). Three problems were still apparent: the loads analyses, Dornier's requests for additional funding, and concerns about IPS performance. Despite both sides' hesitancy to abandon the existing IPS design, it became increasingly evident during the next few months that a complete redesign was probably necessary. On February 5 and 6, 1981, Bignier met with the new NASA Program Director, Jim Harrington (I had retired at year's end), to discuss the consequences of the latest 5.7/5.8 Shuttle loads on the IPS program. In particular, Bignier was anxious for NASA to explore whether relief could be obtained by reducing the number of reflights or the lifetime of the IPS or by operational constraints that would lessen the loads impact. There was also considerable discussion about the impact (possible delay) on the second Spacelab mission. Meanwhile, ESA and its contractors continued to look at alternate design approaches to meet the loads and safety concerns.

Figure 75. Instrument Pointing System assembled for testing at the Dornier facility in Freidrichshafen, West Germany, October 1980. Note the counterweights necessary for 1 g testing.



Finally, on April 8, Pfeiffer wrote to John Thomas, the new NASA Spacelab Program Manager at Marshall (Jack Lee having moved up to the position of Deputy Director of the center), advising him of the April 3 selection of a new design concept for IPS. ESA had concluded that the existing mechanical design would have failed at several critical sections from the structural loads. The basic electronics concept, however, would be retained. The new design would withstand the mechanical environment, have a simplified drive unit, provide better approaches to the safety concerns, and provide better performance by increasing the overall stiffness of the system.

The June 26 Quarterly Progress Meeting at Dornier was the next important milestone in the IPS program, and it covered a potpourri of subjects. Dornier presented the details of its new design concept (fig. 76) and the results of recent hardware testing. Harrington presented a summary of the recently successful first flight of the Space Shuttle. All were relieved to hear that the measured liftoff and landing loads were nominal. Finally, Professor Guenter Brueckner from the U.S. Naval Research Laboratory summarized the latest user requirements for IPS performance. More important for the program, this meeting seemed to result in converting Brueckner from a skeptic to one of IPS's strongest supporters. This was an impor-

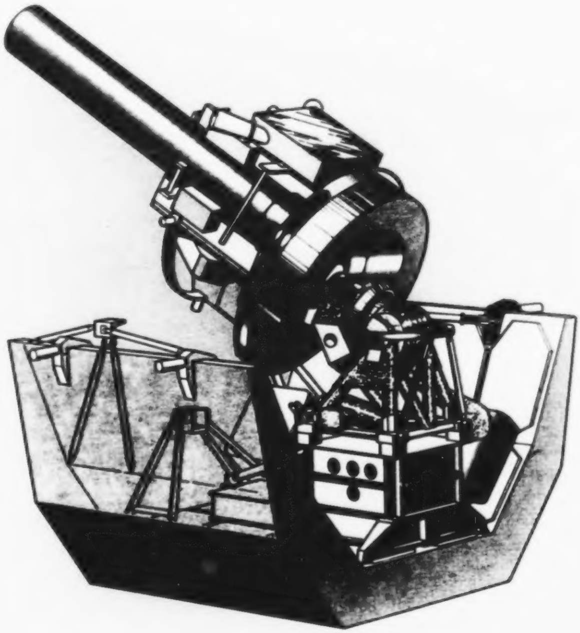


Figure 76. New design concept for the Instrument Pointing System showing the proposed Spacelab 2 experiments mounted on the payload attachment ring.

tant accomplishment, since he was scheduled to be one of the first users of the system with his solar ultraviolet spectral irradiance monitor and solar ultraviolet high-resolution telescope and spectrograph on the Spacelab 2 mission.

In order to keep a reasonable balance in this story of Spacelab development, the next 4 years of IPS development are not treated in the same detail as the period up to 1981. Once the decision had been made to redesign the mechanical system, the corner had been turned. Although many detailed technical and programmatic problems would continue to surface, a feasible system was now in sight and would be delivered by Dornier and ESA. Along the way, NASA and McDonnell Douglas Technical Services Company would help resolve numerous problems with the payload clamp assembly, new stress corrosion problems identified during late qualification tests, seemingly endless quality problems with the rate gyro electronics, software problems (in trying to fit the necessary control software into the very limited fast loop computer), and the critical need for missing thermal vacuum and life testing of the integrated clamp and separation mechanisms.

In addition to design changes, a major contractual change was also made by terminating the MBB support to Dornier. As pointed out, the sizable proportion of effort assigned to MBB had caused a formidable management challenge from the beginning of the program. As technical and funding problems mounted, the relationship between Dornier and MBB became increasingly difficult. In the new design approach, Dornier would be a prime contractor in the normal manner, with responsibility for the primary technical effort. NASA, too, made a management change by assigning Gene Compton from MSFC as its full-time liaison at Dornier. This would ensure efficient and timely exchange of information between Dornier and the NASA analysis, payload, and operational teams and contractors.

The final design of the IPS (figs. 77 and 78) consisted of 12 major elements: (1) a gimbal support structure with replaceable column for vertical positioning of the center of rotation, (2) three drive units containing redundant brushless DC torquers and resolvers, (3) a payload gimbal separation mechanism to separate the IPS and payload during launch and landing, (4) a gimbal latch mechanism to lock the gimbal system for launch and landing, (5) an equipment platform for gimbal-mounted equipment, (6) a supporting framework to serve as the primary support structure for the integrated gimbal system, (7) a data control unit to provide fast loop control functions, (8) a power electronics unit to provide power and power conversion, (9) a rate gyro package, (10) a payload clamp assembly to provide three-point clamping of the payload for launch and landing, (11) an optical sensor package for star or Sun acquisition and tracking, and (12) a bumper device to provide a structural stop for the gimbal system. The development of these elements would require the combined talents, not only of Dornier, but also of its 11 subcontractors in Europe and 11 more from the U.S.

After Dornier's redesign concept was given a go-ahead in July 1981, a new Preliminary Design Review was held in September 1981, a Spacelab 2 Interface Review in January 1982, and a Critical Design Review (CDR-B) of the redesign in August 1982. Following this, effort on the IPS follow-on procurement unit, which had been temporarily halted, was restarted. Subsystem integration of the new

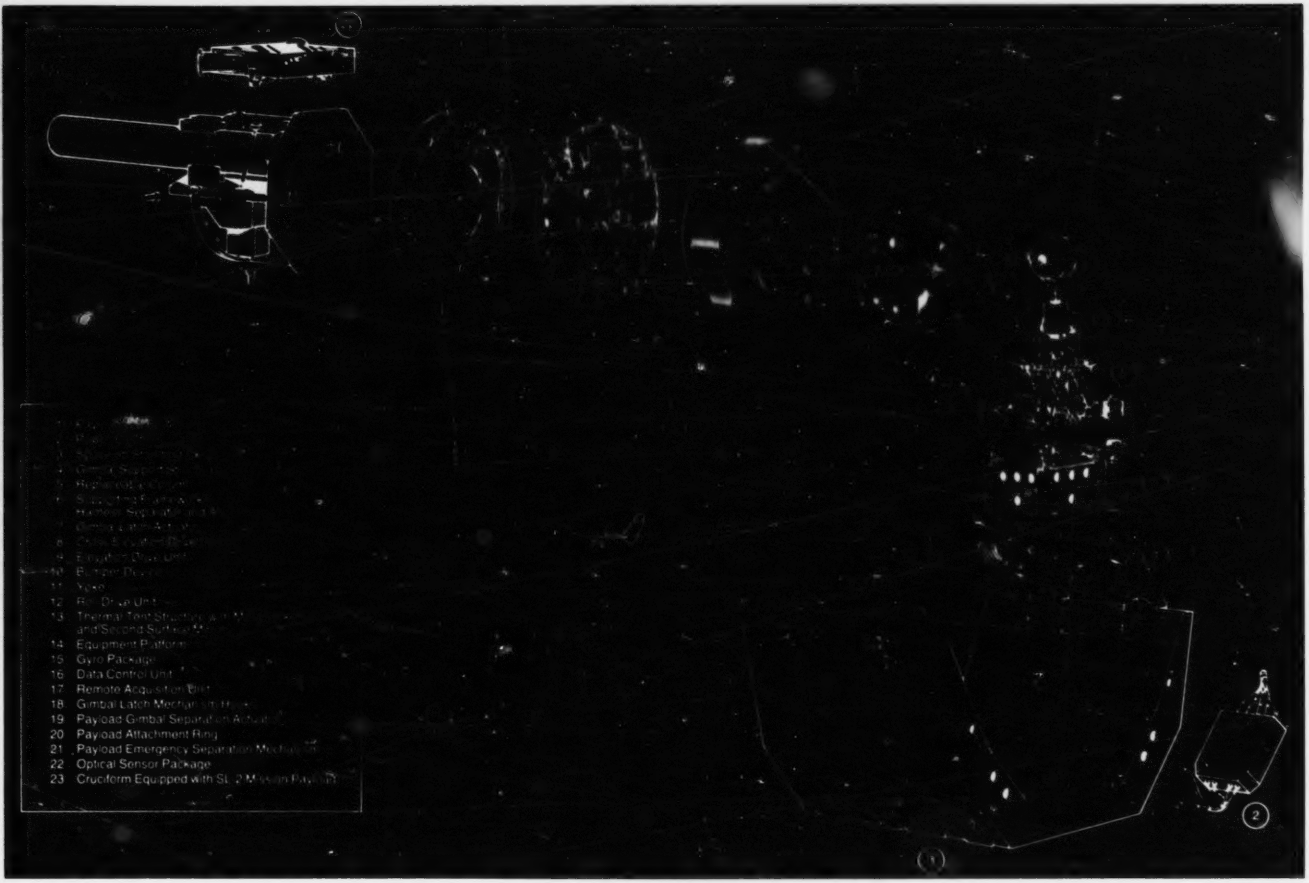

4 Gimbal Support
5 Replaceable
6 Supporting Framework
Harness Separation and
7 Gimbal Latch Actuator
8 Cross Elevation Drive
9 Elevation Drive Unit
10 Bumper Device
11 Yoke
12 Roll Drive Unit
13 Thermal Tent Structure with
and Second Surface Mirrors
14 Equipment Platform
15 Gyro Package
16 Data Control Unit
17 Remote Acquisition Unit
18 Gimbal Latch Mechanism Hook
19 Payload Gimbal Separation Actuator
20 Payload Attachment Ring
21 Payload Emergency Separation Mechanism
22 Optical Sensor Package
23 Cruciform Equipped with SL 2 Mission Payload
2
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Figure 77. An exploded view of the final design of the Instrument Pointing System, configured for the Spacelab 2 mission.

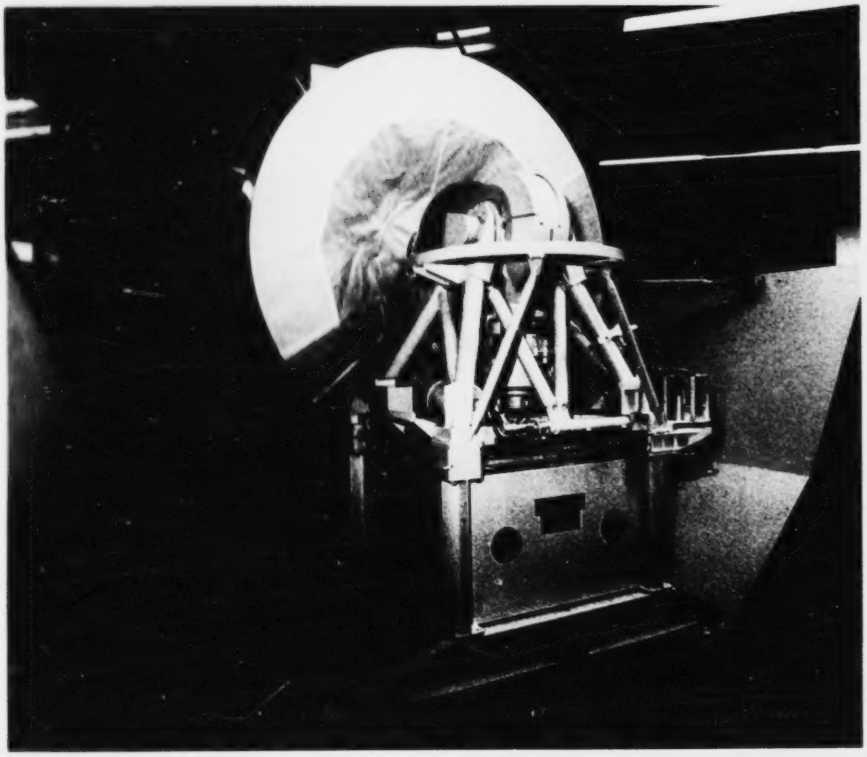


Figure 78. Mockup of the redesigned Instrument Pointing System.

system began in May 1983 and the Acceptance Review of the first flight unit was completed in time for delivery to KSC on November 13, 1984. The last few months of checkout were fraught with debates about the state of readiness of both the hardware and software and the adequacy of documentation and operating instructions, with NASA caught in a dilemma concerning whether to push for completion of qualification testing and system verification in Europe prior to delivery or to push for early delivery of the hardware to KSC in order to begin payload integration for the Spacelab 2 mission now scheduled for April 1985. Finally, with ironclad assurances from Dornier that all open actions, missing data, and tests would be completed prior to launch, NASA and ESA decided to accept the IPS, ready or not.

As with other elements of the program, certain persons need to be singled out for special recognition. Certainly Peter Wolf, who replaced Colin Jones as ESA Project Manager, deserves a significant share of the credit. He uncovered the problems, searched for the solutions, and directed the corrective actions, working intensely and for extremely long hours, stubbornly refusing senior ESA help. At Dornier, Dr. Helmut Ulke provided top company support and insisted Dornier could (and would) complete the job it had started. At the next level, Kurt Gluitz provided continuing direction and support to the succession of Dornier Project Managers beginning with Ulrich Picker, followed by Juergen Spintig, and Klaus Fahlenbock, who provided day-to-day leadership of the technical team. Dr. Axel Hammesfahr was another key member of the Dornier team in providing analytical design and performance assessments through the life of the development effort. On the NASA side, in addition to Gene Compton, a number of MSFC individuals provided heroic support, notably Jim McMillion, Pat Vallely, John Thomas, and George Townsend (MDTSCO), along with Jim Bodmer of JSC. More than anybody else during the year before and during the Spacelab 2 mission, Ray Tanner of MSFC deserves special recognition for successful resolution of IPS operational problems.

NASA HARDWARE AND FACILITIES

TRANSFER TUNNEL

A major hardware assignment to the McDonnell Douglas Technical Services Company (MDTSCO) was the design, fabrication, and verification of the cylindrical tunnel connecting the Spacelab module to the mid-deck of the Orbiter. The crew would be in the Orbiter during Shuttle launch and landing and would perform eating, sleeping, recreation, and hygiene functions in the crew compartments located therein. The tunnel, shown in figure 79, would provide easy access to the Spacelab module and would also provide for an exchange of atmosphere between the two habitable volumes and a scrubber for removal of toxic gases and odors from the enclosed atmosphere.

Prior to award of the integration contract to MDTSCO in 1977, NASA and ESA had already made important design decisions relative to the transfer tunnel. As early as 1974 both were studying various options for the tunnel's size and location. Initial plans envisaged a number of interchangeable tunnel segments so that the module could be accommodated in a number of locations within the cargo bay. These plans were soon shelved in favor of a two-position approach. Another critical decision was to provide a center entrance to the module, but to locate the primary length of tunnel low in the cargo bay so that the volume above the tunnel could be utilized for other payload needs. This dictated a joggle, or offset section of the tunnel, a requirement which would later cause considerable problems for the structural engineers.

By July 1977 a Preliminary Requirements Review of the tunnel had been held, and design and development of critical elements were initiated. The most difficult task, from the outset, was to develop a pair of flexible toroidal sections to be placed at each end of the tunnel, which would minimize the transfer of loads between the tunnel and its adjoining structural elements. MDTSCO assigned this task to the Huntington Beach division of McDonnell Douglas, which in turn enlisted the consultant support of the Goodyear Aerospace Corporation with its expertise in flexible structures. By June 1978, McDonnell Douglas reported that it was having problems

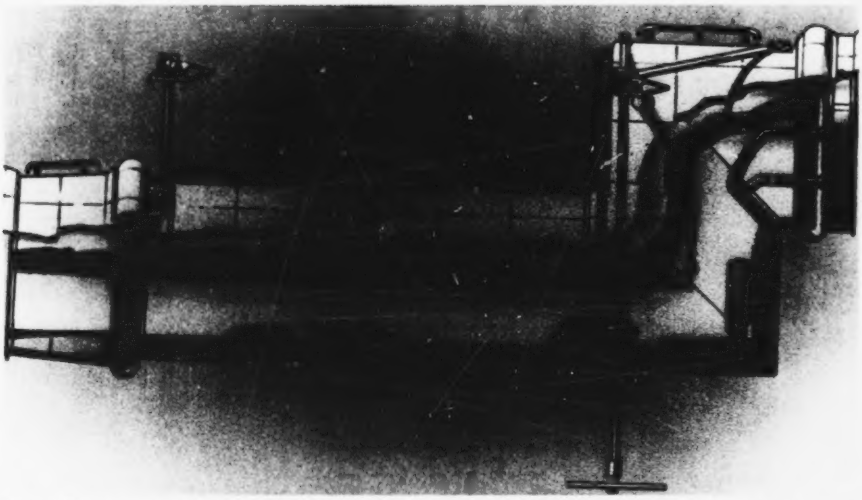


Figure 79. Layout of the Spacelab transfer tunnel showing the full-length version for aft location of the module.

in both the design and fabrication of the flexible tunnel sections. Longitudinal deflections could be accommodated quite easily, but misalignments or deflections which caused torsion or shearing of the toroidal section resulted in unacceptable loads. In addition to a nonmetallic approach, McDonnell Douglas was considering an all-metal design of spherical joints with a telescoping feature, as well as a metal bellows approach, either of which would result in a significant weight penalty. In the meantime, MSFC had conducted successful tests of the atmospheric scrubber system, which would be incorporated into the tunnel design and which employed a 2 percent platinum-on-charcoal catalyst to remove contaminants.

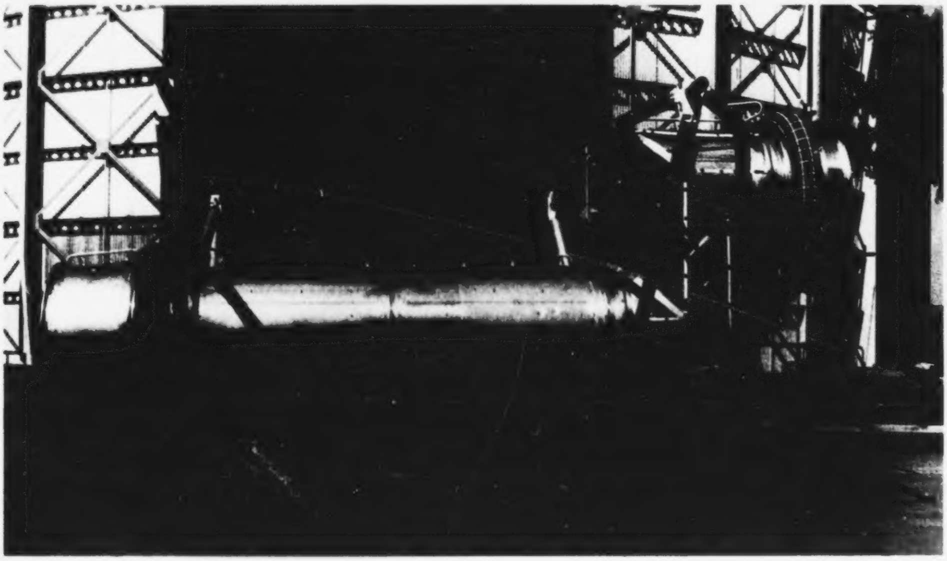
One factor that complicated tunnel development was the on-again, off-again nature of the program. As the primary Spacelab and Shuttle programs experienced schedule delays, NASA continued to adjust its peripheral equipment schedules to reduce current funding requirements. Thus a tunnel development program which probably could have been completed in 2 years stretched over 7 years. Responsibility for the flexible sections was taken away from the McDonnell Douglas group and was contracted for directly with Goodyear. By April 1979, good progress was finally reported in the development of the flexible sections. A single convolute bellows constructed of a composite material of two plys of Nomex cord embedded in Viton rubber seemed to do the trick. Specific solutions had been found to a number of critical problems: proper adhesion of the Viton rubber to the Nomex cord, acceptable material flammability and toxicity characteristics, uniform Nomex cord separation during the molding process, and agreement on both tunnel-to-module and tunnel-to-Orbiter interface loads. A development test program was under way to demonstrate safety, life cycle, damage susceptibility, and burst conditions.

The development test program of the tunnel "flex unit" was successfully completed in April 1979. The positive results provided a high degree of confidence in the inherent safety of the design. Preliminary Design Review activities previously terminated due to flex unit development problems were resumed and satisfactorily completed in May 1979. Included was a crew walk-through of the tunnel mockup at McDonnell Douglas in Huntington Beach.

The flexible section was not the only difficult design challenge in the tunnel development effort. The joggle, resulting in a modified Z-shape to the rigid portion of the tunnel, also challenged the McDonnell Douglas engineers, because when pressurized, the tunnel tended to straighten out and to rotate like a lawn sprinkler. The original concept for joggle fabrication was to make two parallel and diagonal saw cuts of a cylindrical section and then rotate the two ends 180° and reweld them to the diagonal section. Along the vertical center line of the tunnel, where the tunnel sections come together at a 90° angle, very strong joints could be obtained; but on the sides where the sections butt together, the joint was inherently weak. Eventually, elliptical reinforcement rings had to be added to these joints to provide the necessary strength. At the sides of the tunnel, these rings were as much as 10 inches thick to maintain the shape and to prevent a catastrophic fracture in the area (fig. 80).

Support struts were designed to mount the tunnel in the cargo bay independently from the Spacelab module. The struts had to withstand takeoff and landing loads and were responsible also for restricting the tunnel from any rotation due to

Figure 80. Completed transfer tunnel unit at the McDonnell Douglas facility in Huntington Beach, California.



pressurization. However, pressure tests revealed that near the vertical center line sufficient deflections did occur to permit leakage above the design limits; in fact, some of the bolts at the attachment flanges were elongated. The solution was to double the number of bolts in critical areas and switch to high-strength bolts.

The final challenge to the tunnel design, as it was to the primary Spacelab structure, was the increased loads from the Shuttle. This resulted in several redesigns of the structural components before final fabrication and testing. Drastic actions such as addition of a third flex unit or depressurizing the tunnel during critical flight loading conditions were considered, but eventually no configuration or hardware changes were necessary. An updated Orbiter deflection analysis, tighter tunnel dimension tolerances, additional flex unit testing, and more stringent temperature constraints on the flex unit were combined to substantially reduce the loads transmitted from the tunnel to the module. Resolution of this problem paved the way for the tunnel Critical Design Review, finally completed on September 16, 1980, after another hiatus of several months to await program funding. The CDR was noteworthy in that the planned board meeting was canceled because there were no discrepancies requiring senior-level action. Some of the most significant discrepancies would require a continuing loads impact analysis, possible redesign of the tunnel's unique bridge fittings, additional thermal analysis of the flex sections for the reentry condition, a worst-case analysis of ionizing radiation during solar flare activity, and follow-up work to resolve ground support equipment shortages.

Once the design problems were solved, the actual fabrication problems seemed minor. Of course the welding of the joggle section was a challenge, with its several hundred feet of welding. Many weeks were spent chasing down voids and flaws, then grinding and rewelding, but these were the kinds of problems that had been solved before. In addition to the basic structure, the tunnel consisted of a fairly simple environmental control system with a circulating fan, scrubber, valving, filters, screens, and a lighting system. The entire assemblage was delivered to KSC by early 1982, ready for processing for the first Spacelab mission (figs. 81 and 82). The McDonnell Douglas team led by Merryl (Butz) Toles, Hal Mitchell, Al German, Steve Wallis, and Tom Quintana could take considerable satisfaction from the successful completion of this critical element of the Spacelab system.

VERIFICATION FLIGHT INSTRUMENTATION

The second major hardware assignment to MDTSCO was the development of instrumentation for the verification flight tests planned for the Spacelab 1 and 2 missions. Spacelab 1 would verify operation of the module system and Spacelab 2 would verify operation of the pallet-only configuration. As in the case of the tunnel, NASA and ESA had made several decisions on the VFI before MDTSCO came on board in 1977. John Thomas, then NASA's chief engineer for the Spacelab Program Office at MSFC, had given the first detailed requirements to the Joint Spacelab Working Group at its meeting of July 12, 1974. He presented the parameters to be

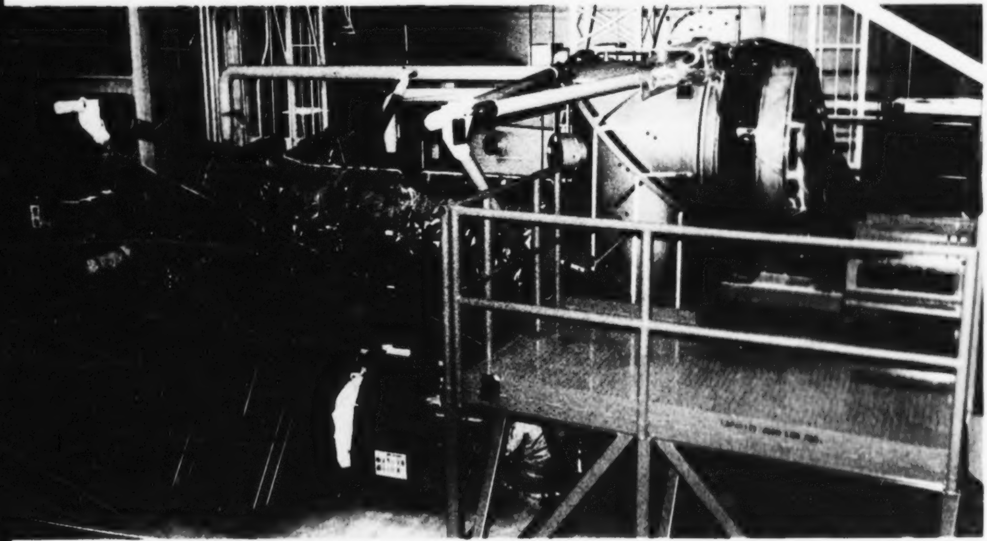


Figure 81. Transfer tunnel at Kennedy Space Center being readied for the Spacelab 1 mission.

Figure 82. Transfer tunnel installed at the Kennedy Space Center Operations and Checkout Building test stand with the Spacelab 1 module.

measured, the type of test equipment, power and weight requirements, and summary mission timelines. Measurements to be included were temperature, voltage, current, acceleration, strain, deflection, pressure, contamination, vibration, and acoustics. These requirements were the product of an MSFC study, documented in "Spacelab Flight Test Requirements Mission #1" dated July 9, 1974. The proposed equipment amounted to some 1250 pounds with power requirements less than 400 watts during ascent and descent and less than 1 kw on orbit. It was understood from the beginning that the VFI should have top priority on the first two Spacelab missions, but useful science would also be obtained. It was not known at this time who would provide funding for the VFI.

By the December 1974 Joint Spacelab Working Group meeting, a preliminary version of a VFI plan had been prepared by MSFC. The use of the engineering model module as a payload on an early Shuttle flight was being considered by MSFC, but ESA Project Manager Stoewer objected strongly, and no further mention can be found of this proposal. By March 1976, Thomas presented an updated plan for verification flight test requirements. His approach now was to treat the VFI package as much like an experiment as possible. Stoewer was concerned now with the large number of sensors and the possibility that some would have to be installed at ERNO. By this time it was apparent that NASA would be responsible for VFI funding and implementation.

When MDTSCO came on board, it was assumed that the VFI would be in good hands, in view of McDonnell Douglas' extensive experience in the instrumentation of expendable launch vehicles for MSFC, in particular some of the Saturn upper stages. By August 1977, the new Spacelab contractor had successfully supported the NASA team in conducting a Preliminary Requirements Review for the VFI. MSFC, also responsible for management of the Shuttle external tank, solid rocket boosters, and main engines, was optimistic that much of the instrumentation needed for the Spacelab VFI could be obtained by adding extra units to the purchase orders for instrumentation on these other programs. The MSFC team also felt that much of the desired test data could be obtained from the operational Spacelab systems which included considerable instrumentation and even from some of the experiments of the payload. By April 1978, Luther Powell reported to the Joint Spacelab Working Group that a revised VFI requirements document was near publication, including changes resulting from several ESA proposals. The bad news was that the weight of instrumentation had increased 50 percent to almost 1900 pounds, even though a nuclear radiation monitor weighing more than 100 pounds had just been deleted. In June, the Preliminary Design Review was completed, but it was not until July and November 1979 that a two-part CDR was completed for the VFI for Spacelab 1.

The major problem in VFI definition and development was that the job was underestimated. What had looked like a straightforward design at times became a nightmare. Changes in the Shuttle environment, always seeming to get worse, required ever larger sensors. The sensors thought to be available from other programs were either not available or not applicable, or, even worse, had increased in cost by factors of 3 and 5. Instrument contractors who had lost money on Shuttle procurements wanted to recoup on Spacelab. Since one of the ground rules was to develop no new instruments, the job became one of shopping around to find the right instrument, then juggling all the equipment to make it fit. As a result, the cost of the VFI program skyrocketed.

Another contributing factor to the cost increase was the difficulty MDTSCO encountered in obtaining detailed design information from the European builders of the Spacelab. In many cases, the contracts did not require that detailed drawings be provided to ESA or ERNO, and all rights were held by the European co- or subcontractors. The problem here was also related to NASA's desire for MDTSCO to be capable of providing sustaining engineering for all Spacelab hardware as quickly as possible during the operational phase of the program. Naturally, the European contractors, hopeful of playing a substantial role in the operational period, were not inclined to turn over all their design details to MDTSCO. ESA and its contractors continued to protest that NASA demanded too much documentation, and MDTSCO could not figure out how to install sensors on hardware for which it had no drawings. A solution was finally obtained when NASA negotiated with ESA to purchase the detailed drawings. The problem then became one of finding out what was available at the European contractors' sites, a problem that required of NASA and MDTSCO engineers considerable on-site searching. To complicate matters further, the detailed drawings could be in any one of seven languages, depending on the contractor involved.

Unlike the tunnel effort, which was sublet to Huntington Beach, the VFI effort was conducted by the MDTSCO team at Huntsville. As if the problems described above were not enough, the Huntsville team faced the growing pains of getting a new organization under way. In order to keep its costs low and in keeping with its low bid, MDTSCO established an artificial restraint on the average salary that could be paid to new hires. In view of the fact that the new Shuttle booster processing contractor had absorbed most of the good local talent, it was difficult to obtain good talent for MDTSCO. If they paid a high price to obtain a particularly good engineer, they had to balance that by hiring one or more very low cost personnel. In so doing, MDTSCO made a number of hiring mistakes that took some time to correct. To further complicate the situation, NASA informed MDTSCO almost immediately that it did not have sufficient funds to pay for the effort that had been bid and the entire contract would have to be stretched out. Later, at the low point in the VFI development when it seemed that NASA had completely lost faith in the MDTSCO team and its ability to control cost escalation on the program, MDTSCO called for an objective review of its efforts on the VFI. A MSFC review board chaired by Ray Tanner was convened, which concluded that MDTSCO should be given a clean bill of health.

Despite these problems, the VFI was eventually defined, and procurement of sensors and equipment began. By late 1981 installation of VFI equipment in rack 3 of the module was initiated and fabrication and installation of ground support equipment for the VFI was almost completed. By early 1982, cable routing and installation of equipment could begin on the flight pallet and module, which by now had been received at KSC. Although many people contributed to the successful completion of this difficult phase of the Spacelab program, Bob Brotherton of MDTSCO and Dr. Wayne Littles of MSFC played key roles in VFI planning, and Ray Nemi of MDTSCO and Cecil Messer of MSFC deserve much of the credit for translating the plans into workable hardware.

A Design Certification Review on the verification flight tests and verification flight instrumentation was completed in April 1983. From that point forward, VFI was handled as an integral part of the Spacelab 1 mission.

OPERATIONS AND CHECKOUT BUILDING

Up to this point, little has been said about activities at KSC in support of the Spacelab development effort. That does not mean that KSC was not instrumental in early Spacelab planning and resolution of problems encountered in the various program reviews. In fact, from the start of the program, a small KSC Project Office headed by Jack Dickinson provided considerable support to the MSFC Program Office, including the assignment of Paul Kolasky as liaison representative and technical specialist on launch operations during the formative years of 1974–1976. The KSC team provided key contributions to every operational decision.

One product of the KSC project team was development of a Spacelab/Facilities Interface Control Document, which was approved by ESA Project Manager Pfeiffer and NASA Program Manager Lee in early 1977. In the meantime, preliminary planning had been under way on modifications to the Operations and Checkout Building, which would serve as the primary U.S. integration facility for Spacelab. Earlier chapters commented on NASA's initial plans to process some of the early hardware through MSFC and to integrate many of the Spacelab payloads (Level IV) at remote sites. Gradually, however, more of the integration effort was concentrated in the KSC facility.

The O&C Building had been built as the checkout facility for Apollo spacecraft and consisted of three primary elements: a huge high-bay clean room that was as long as two football fields; an adjoining area of laboratories, shops, and overlooking rooms for support equipment; and an adjacent office building. Before the high-bay area could be outfitted for Spacelab use, it was necessary to strip out most of the existing workstands and equipment (two Apollo environmental chambers and an Apollo Telescope Mount clean room were left in place). Design of the facility modifications, workstands, and ground support equipment to be provided by KSC was begun in 1976, and by 1978 the new facility was ready for use (fig. 83). The efficiency and skill with which this transformation was implemented was remarkable. After wrestling with myriad problems and delays with the Spacelab flight components, it was hard to believe that this portion of the program could be accomplished with so few troubles. Actual facility modifications began in September 1977 when the old floor of the high-bay area was removed and replaced with a slab more than twice the thickness of the original in order to withstand the high floor loadings in the vicinity of the workstands. Construction then began on modifications to the facility support systems and on the several workstands (integration stands, pallet

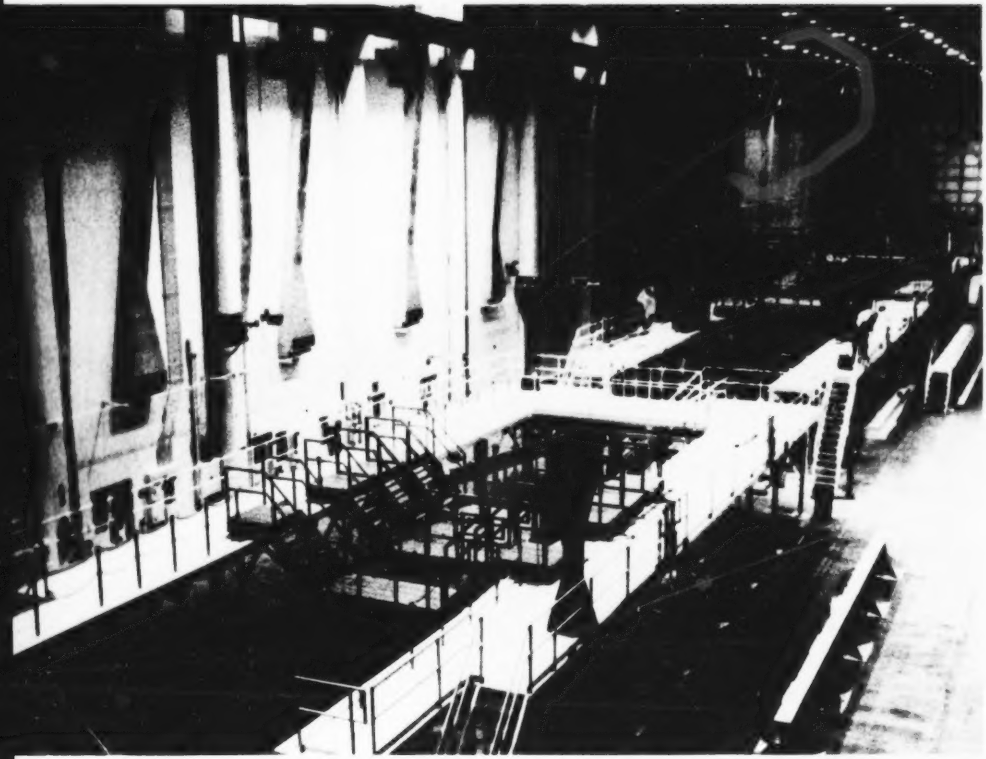


Figure 83. Overview of the modified Operations and Checkout Building at Kennedy Space Center with Spacelab test stands in place.

stands, rack stands, end-cone stands, and engineering model stands). One of the most difficult decisions was how many stands to provide, since the Spacelab traffic model was so uncertain. The final layout showed room for four integration stands, end to end; however, only two would be built initially for Level III/II checkout of Spacelab and a third for a Shuttle cargo integration and test equipment (CITE) stand, where Shuttle payload could be checked out horizontally with prototype Shuttle interface hardware. A similar CITE stand would be built in another building for vertical checkout of Shuttle payloads. Initially, only one set of Shuttle subsystems would be provided to be shared by the two CITE facilities.

Perhaps the most difficult challenge in modification of the high-bay area was to design a room that could be maintained at a 100-K cleanliness level. The finish on the floor was the key to this problem, and eventually the solution was found (an epoxy-based coating). Once completed, the high bay provided an efficient area for the planned processing of Spacelab. When the decision was made to perform most of the Level IV activities in the clean room, the support facilities were easily housed in the area reserved for the fourth integration stand. Although at times this area would become quite crowded, until there was a significant increase in the Spacelab launch rate, this arrangement would be workable.

SOFTWARE DEVELOPMENT FACILITY

Another key facility, in this case for MSFC, was the facility to be built by MDTSCO for development and maintenance of program software. There are three fundamental software operating systems in the Spacelab program: the ground computer operating system (GCOS) developed by BTM, the subsystem computer operating system (SCOS) developed by MATRA, and the experiment computer operating system (ECOS) developed by MDTSCO with IBM as major subcontractor. The Software Development Facility was required in order for MDTSCO (and IBM) to prepare the ECOS software and to create applications programs and integrated flight tapes for each mission. Because Spacelab uses a European data system, it was necessary for MDTSCO to procure ground versions of the flight data management system from Europe.

MDTSCO began design of the Software Development Facility (SDF) in 1977, obtained a stand-alone MITRA 125 S computer in early 1978, conducted Preliminary and Critical Design Reviews later in 1978, and had the complete facility operational at the IBM Huntsville complex in November 1979. In addition to providing a duplication of the Spacelab system, the SDF simulates all the Orbiter interfaces and also has the capability to model the experiments that will fly on Spacelab. The facility has since been moved on-site at MSFC (fig. 84), a second set of hardware has been added, and a capability has been provided for maintaining the ground computer operating system as well as the experiment and subsystem computer operating systems. With all computer systems operating, the SDF can duplicate the entire flight/ground software system. This provides a capability to test the interaction among systems, a capability previously possible only at KSC shortly before launch. Further capability was provided by the incorporation of systems to model the Instrument Pointing System, so that the same kind of software development and maintenance can be accomplished for the IPS as for the basic Spacelab.

The flexibility of this facility was demonstrated during the Spacelab 1 mission when a problem occurred with a remote acquisition unit. Some real-time fixes were made to the software to allow it to ignore the erroneous inputs from the RAU and to salvage much data that otherwise would have been lost. There is no question that the SDF will continue to play a critical role in future Spacelab missions.

SPACELAB SIMULATOR

Early planning for Spacelab envisioned a high-fidelity mockup of the Spacelab module to be used for crew training and familiarization. Unfortunately, the high cost of such a mockup and its questionable value to the program in view of the cost resulted in NASA's canceling its plans to purchase such a unit from ERNO. Instead, attention focused on procurement of a Spacelab Simulator which would provide operating subsystems and a more suitable training device for JSC flight controllers

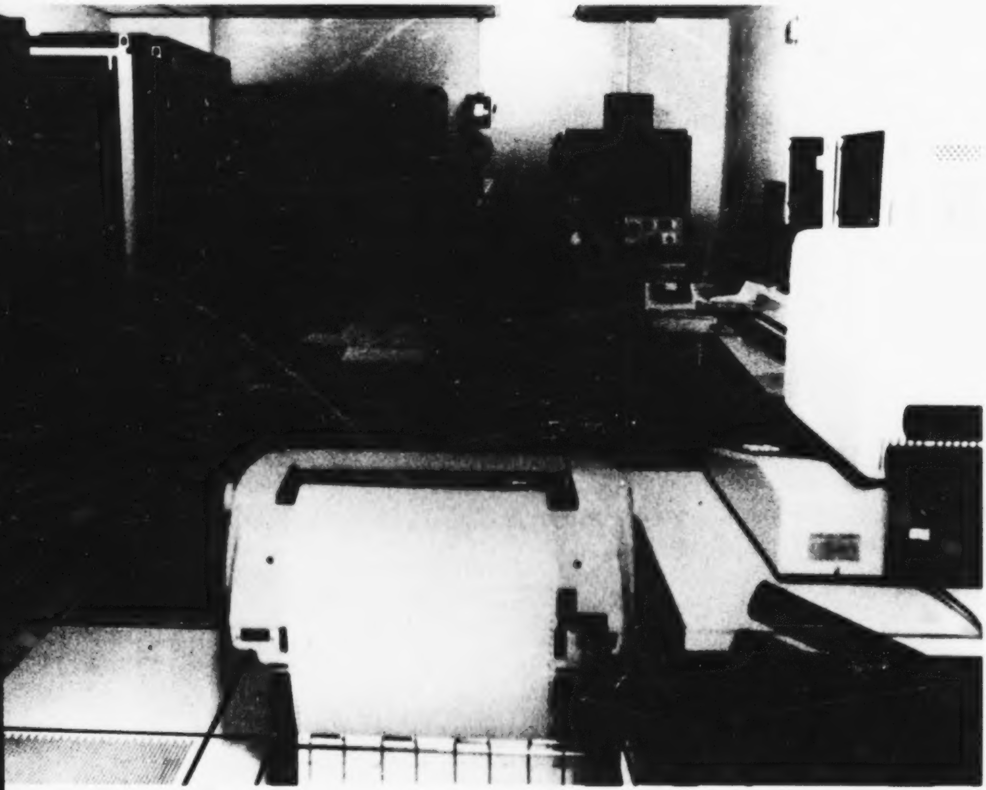


Figure 84. Spacelab Software Development Facility at Marshall Space Flight Center.

and Spacelab flight crews. Already in April 1976, Merlin Merritt, who would later play a key role in training Spacelab crews at JSC, was lobbying for a simulator to become the primary facility for training in Spacelab systems, crew integration, and crew/ground integration and in the development and validation of onboard procedures. At my August 1976 Program Director's Review, John Waters of JSC, who would be responsible for development of the Spacelab Simulator, presented a plan for procurement of a simulator which would operate alone or in conjunction with the Shuttle Mission Simulator and the Mission Control Center at Houston to produce a high-fidelity mission simulation.

ESA and ERNO responded to the challenge, noting that, although the functions were different, approximately 80 percent of the pieces intended for the high-fidelity mockup could be used for the simulator. NASA wanted to cooperate on this matter, but found it difficult to accept the proposition that ERNO, with its lack of experience, could provide a simulator comparable to those developed in the U.S. for previous manned programs. Instead, ERNO was urged to team up with a U.S. simulator contractor in the planned competition.

This approach seemed to work. In response to a NASA RFP, a proposal was submitted by Link, a division of the Singer Company, in collaboration with ERNO. Link's proposed design for the Spacelab Simulator is shown in figure 85. After evaluation by JSC, a formal contract agreement was signed on January 30, 1978 and development began, with ERNO to provide the scientific airlock mockup for the simulator and data support to Link. ERNO's decision to fabricate the scientific airlock simulator in its own facility was a little surprising, since in the mainline Spacelab hardware, Fokker was responsible for development of the airlock and Aeritalia had manufactured the airlock structure. The Spacelab Simulator was to cost about $6 million, a somewhat arbitrary figure established by the NASA Headquarters Program Office after many arguments with JSC about the degree of fidelity that should be provided by the simulator. This lack of fidelity remained a long running issue within JSC, from the Director to the flight crew, ameliorated somewhat by the approval of a Spacelab single system trainer. In particular, the Headquarters office insisted that provision for simulation of the mission experiments should not be provided, fearing a repeat of the expensive training costs of the Skylab mission on every flight of the Spacelab.

The marriage of convenience between Link and ERNO would not prove to be smooth. No sooner had the agreement been signed than Link started to worry about the devaluation of the dollar and the attendant increase in cost of the ERNO support. As with other phases of the program, agreement to provide data, and securing acceptable data, were two different matters. Nevertheless, an interim report in August 1978 indicated that development was progressing satisfactorily except in areas impacted by the data problems. Delivery of the simulator to JSC was projected for March 1979 with acceptance to follow a year later.

Continuing problems in securing adequate data from Europe and delays in the ERNO airlock delivery caused schedule slips and consideration by JSC and Link about canceling the ERNO airlock. The latter resulted in some fairly strong exchanges in late 1978 and early 1979 between Bignier and me, although by now we had become close friends. JSC had proposed termination of the total ERNO subcontract. I rejected this proposal initially and agreed to give JSC additional funding to cover the ERNO escalation due to dollar devaluation alone. Later I informed Bignier that NASA would be forced to cancel the remainder of the ERNO effort because of the tight funding situation for NASA in trying to bring all elements of the Space Transportation System to operational readiness and in the belief that canceling the ERNO simulator contract would not severely damage Spacelab's operational capability. Fortunately for the program, ERNO responded quickly with a more reasonable fixed-price proposal to complete the airlock simulator, and we decided against cancellation.

By April 1979 it appeared that the Link/Singer simulator hardware would be delivered to JSC by summer, after which integration and software development efforts would be initiated. It was hoped that the simulator would be ready to support training in mid-1980. ERNO completed its work on the airlock simulator, and a very

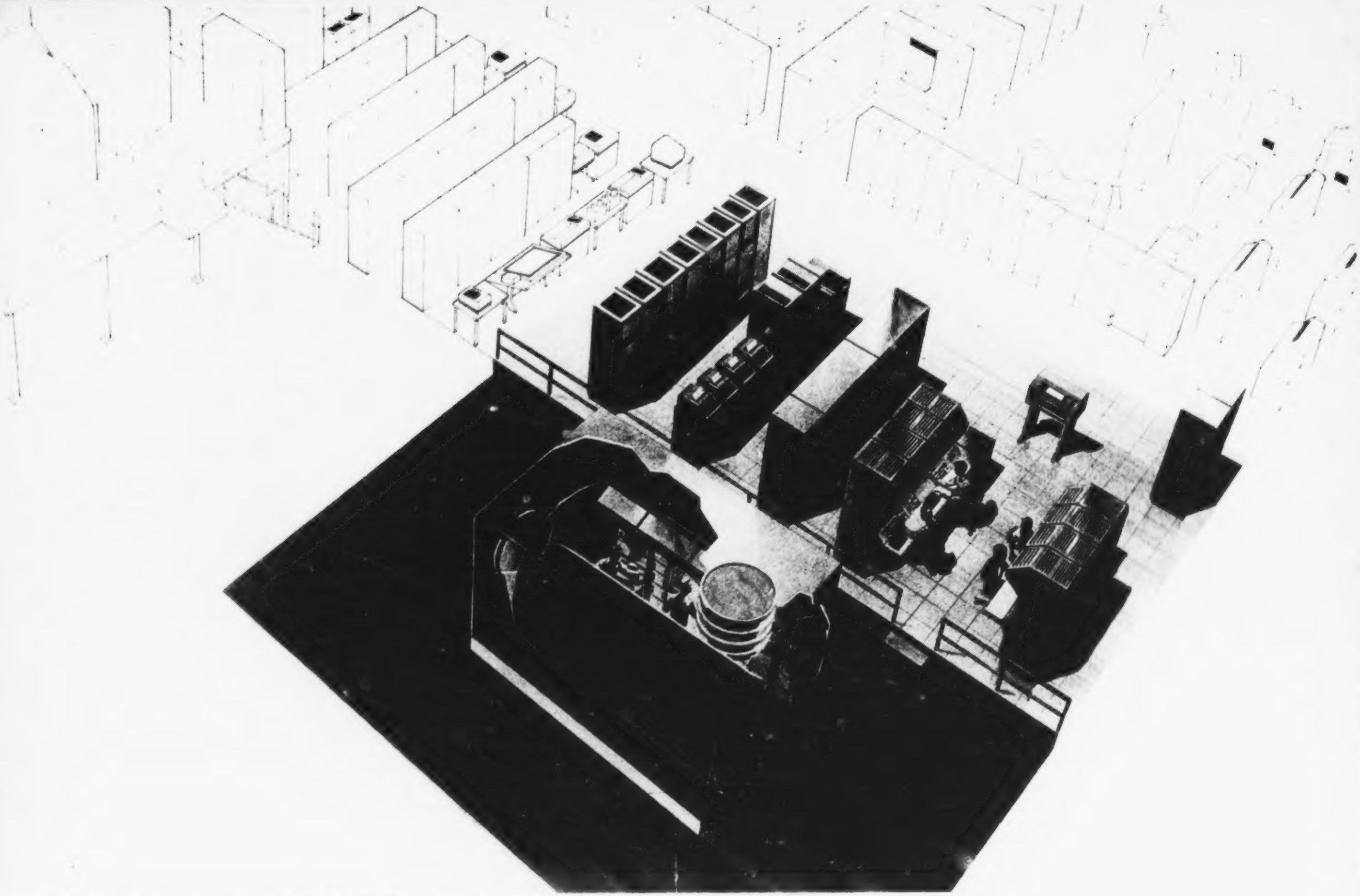
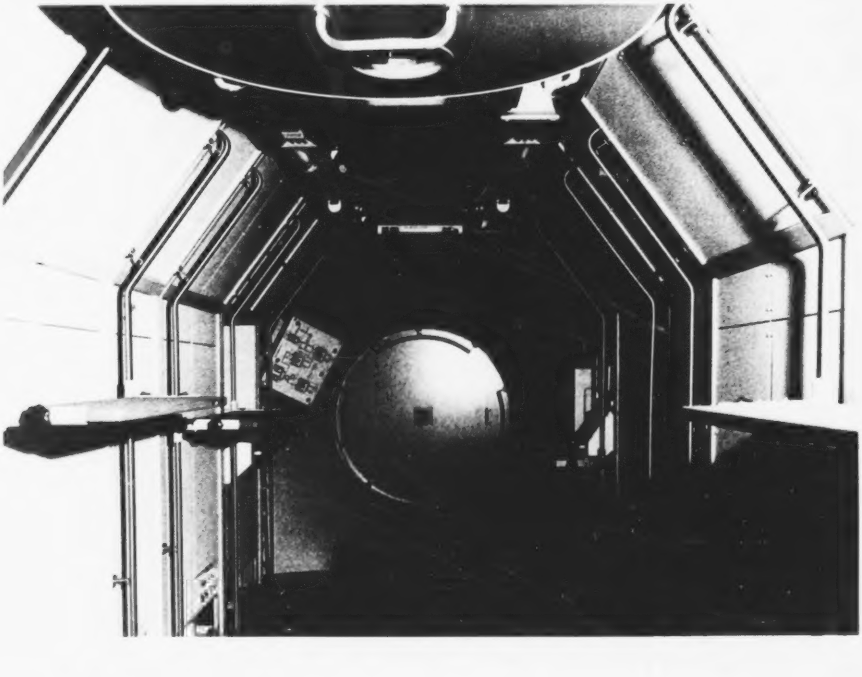


Figure 85. Artist's conception of the Link Company's proposal for the Spacelab Simulator.

successful acceptance review was held at Bremen in June 1979. The airlock was then shipped to Link at Binghamton, New York, where it was integrated into the overall simulator system. The total hardware system was shipped to JSC where it was accepted in September 1979. This included the crew station, an instructor operator station from which training operations would be controlled, and supporting computer equipment. It now appeared that crew training could begin about September 1981. As usual, this would turn out to be an overly optimistic projection. More than 3 years would be spent developing software, performing functional updates, integrating the hardware and software, and conducting final acceptance reviews.

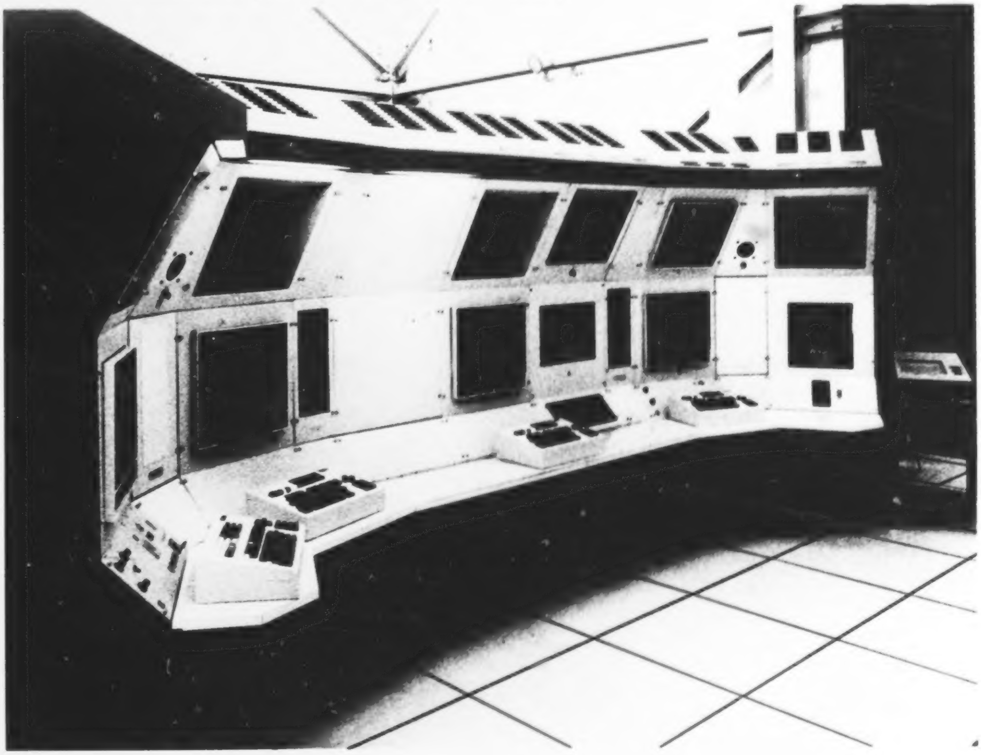
The delays in the simulator program should not be blamed solely on European problems, however. As the planned launch schedule for Spacelab 1 slipped, NASA continued to stretch out the simulator schedule, along with everything else being developed in the U.S. in order to reduce current funding. The net result of all the slippages and modifications to the basic simulator resulted in an increase of the total cost of the simulator to almost $12 million, twice the original proposal. However, the final simulator (shown in figure 86), which internally had the appearance of a long module, provided an excellent training device for the crew and flight controllers in Spacelab systems operation and in developing effective procedures for the

Figure 86. Interior of the Spacelab Simulator at Johnson Space Center.



early Spacelab missions. In addition to the airlock and subsystem controls, the simulator contained a work bench, storage compartments, environmental control system components beneath the floor, equipment and gauges on the forward end cone, and air controls for the various racks. The test conductor panel is shown in figure 87. Except for the lack of experiments, which were eventually simulated in a companion Payload Crew Training Complex at MSFC, the Spacelab crew would feel very much at home in this simulator, which was finally accepted in March 1983. When connected to the Shuttle Mission Simulator, the Mission Control Center, the Goddard Data Center, and the Huntsville Operations Support Center and Payload Crew Training Complex at MSFC, it provided a critical link in realistic simulations for the first Spacelab mission. JSC periodically proposed increasing the fidelity of its Spacelab simulator, and because a number of subtle software and procedural problems were encountered with the IPS during the Spacelab 2 mission, these requests were to continue.

Figure 87. Test conductor panel in the Spacelab Simulator.



JOINT CONCERNS

Along with the development of the flight hardware elements and facilities described above, other concerns arose during this time period. Some related to the potential uses of Spacelab hardware; others related to the successful operation of the total system. In some cases, the concerns threatened to undermine the cooperative atmosphere and mutual respect so essential to successful completion of the program.

ESA SPACELAB UTILIZATION PROGRAMME

From the first briefings in Paris in 1970, the European scientific community, encouraged by ESRO and its successor, ESA, devoted a great deal of time to symposia, studies, and workshops considering its role in the use of the Shuttle and Spacelab. Recall that the Spacelab Memorandum of Understanding between ESRO (ESA) and NASA envisaged both cooperative and cost-reimbursable use of the Spacelab by Europe. In April 1977, ESA Headquarters submitted a very ambitious proposal for a Spacelab Utilization Programme to its managing council for consideration. The report addressed the concept, organization, and funding of three alternative programs for European use of Spacelab. The programs provided the equivalent of 14.4, 9.7, and 6.7 European (ESA) Spacelab missions over 1980–1985 at a projected cost of 480, 330, and 250 million accounting units, respectively. (For our purpose, these amounts can be equated to millions of dollars.)

There were many factors complicating this proposal, but the most important was that it attempted to incorporate within ESA's program four Spacelab missions currently being studied by West Germany for its own Spacelab utilization program. Other important concerns were the role of ESA versus NASA in scientific use of the Spacelab, the policy on charging costs to the European users, and the high level of NASA charges for use of the Space Transportation System. In any event, ESA Headquarters considered it essential that a decision be made soon to subsidize two European Spacelab missions to follow the first (joint) Spacelab mission.

The next few years would see many variations on this proposed plan. From the ESA standpoint, however, the April 1977 proposal may have been the high point. It soon became evident that West Germany had no intention of giving up its proposed dedicated missions (except as funding shortages might limit). Furthermore, as the Spacelab development effort burst through first the 100 percent and then the 120 percent cost ceilings, there was little support from the Spacelab Programme Board or the ESA Council to provide additional funding for the utilization program. Finally, and probably most significantly, European industry could not get very excited about a large utilization program for Spacelab because it knew that most of the money would go to NASA for STS operations. It was more interested in activities that would provide jobs for the engineering and manufacturing teams that had been developed and that would prove their capabilities in the Spacelab development program.

REIMBURSEMENT POLICIES

As indicated, the cost to users of the Shuttle and Shuttle-related elements such as Spacelab was to become a very important issue during this period. Early projection of Shuttle operational costs based on minimal knowledge of the system, optimistic turnaround times, and very busy traffic models led to estimates of launch costs of at least an order of magnitude below what had been experienced with expendable launches. As the Shuttle development team began to obtain operational experience and as the traffic model was reduced, real year costs, of a necessity, increased. Even though a considerable increase in cost was due to inflation, it was not enough to allay the concerns of potential users, both in the U.S. and abroad.

The Shuttle user interface organization at NASA Headquarters, under the leadership of Chet Lee, began to address the policies that should be considered for reimbursement for use of the Space Transportation System..It soon became evident that this was a very difficult and emotionally charged subject, requiring the best thinking of Shuttle operations experts as well as financial analysts. What should be the key factors for pricing? How could incentives be maintained for new users? What are standard and what are optional services? Should there be special conditions for users who contributed to the development of the Space Transportation System? Canada and Europe, having developed the Shuttle manipulator arm and Spacelab, respectively, were particularly anxious about the latter question.

Probably the most important impact on the Spacelab program of the initial Shuttle reimbursement policy was the decision to have the cargo bay length used by the payload be the most significant factor in setting the user price. Immediately, users began to look for ways to reduce the length of their payload in the cargo bay, and various entrepreneurs began to design and develop payload carriers for the Shuttle that were shorter than the Spacelab pallets. The SPAS structure developed by MBB and the MPESS (or T-structure) built by Teledyne-Brown for MSFC payloads are two such examples.

In reality, there was never a strong groundswell of enthusiasm from U.S. contractors to lease and fly dedicated Spacelab missions. Although the Battelle Corporation did give some thought to procurement of a Spacelab and acting as a broker for potential users, most people expected that the dedicated Spacelab missions would be funded by NASA science and applications programs. Nevertheless, reimbursement policies had to be established for those users who wanted to lease all or part of Spacelab for their purposes. It appeared that ESA, West Germany, and Japan were probably the most likely users of a dedicated mission, but any group could consider paying to have its experiment carried up on a planned NASA mission by leasing an experiment rack or part of a pallet.

The Spacelab reimbursement policy was incorporated into the STS Reimbursement Guide and delineated such elements as the typical Spacelab flow, standard Spacelab services, categories of Spacelab flights, and optional services. The categories of Spacelab flights were subdivided into dedicated flight, dedicated-element flight, complete pallet flight, and shared-element flight. With the help of these breakdowns and the charts and equations they contained, it became possible to ascertain the price of a Spacelab mission to meet any user's needs.

At the Joint Spacelab Working Group meeting on November 15-16, 1977, ESA expressed concern about the Spacelab reimbursement policy, particularly the high costs, and the fact that ESA was not given preferential treatment by NASA in view of its development of the Spacelab. Chet Lee attempted to defend NASA's position, but it was obvious that, although NASA felt that ESA *was* being given preferential treatment, there was little chance that agreement could ever be reached on that point. Pricing continued to be a dynamic and ongoing activity very much influenced by Congress and also by the pricing of the European Ariane program. A new Spacelab pricing policy has since been approved by the Office of Management and Budget.

DIRECTOR GENERAL/ADMINISTRATOR MEETINGS

These regular meetings of the heads of the two agencies provided a continuing forum for discussion of joint concerns. At their May 18, 1978 meeting, Gibson and Frosch had seemed to be in good agreement on all aspects of the program, and it appeared that both sides were rushing toward a barter agreement on Spacelab hardware for Shuttle launch services. All of a sudden, Gibson sent a letter to Frosch on June 28, which indicated that the entire cooperative framework was falling apart. Gibson suggested that the pending barter was doomed, though not in so many words. He listed complaints apparently laid on him by the Spacelab Programme Board and its members, which included the following:

(1) ESA member states were hesitant to make early financial commitments for four European flights.
(2) No Shuttle procurement had come to European industry and very little manned flight technology had been acquired by Europe.
(3) ESA had expected more cooperative flights using the first Spacelab flight unit.
(4) European industrial involvement in the Spacelab integration contract remained low.
(5) Initial Spacelab procurement was later than foreseen by the Memorandum of Understanding.
(6) Europe was faced with an expensive STS charging policy compared with the 1973 forecast.
(7) ESA would receive decreased charges only under conditions normally applicable to cooperative flights (no proprietary data rights).
(8) NASA was still proceeding with the development of backup Spacelab systems and equipment.
(9) European member states felt that they had exceeded their commitments.
(10) A large number of interface modifications were needed.

(11) Europe was having to provide more hardware than initially foreseen.
(12) Problems were experienced with MSFC's handling of demultiplexer procurement.
(13) NASA tended to consider the relationship between agencies as customer/contractor rather than as a partnership.
(14) Poor attitude was demonstrated by MSFC on ESA's request for help in ERNO negotiations with three U.S. subcontractors.

Although shocked by this assault by Gibson (normally the epitome of a diplomat), the NASA hierarchy met with Deputy Administrator Alan Lovelace to review the charges and decide what action to take. It was decided to set up a meeting between Frosch and Gibson on July 14 and respond to the ESA letter point by point. The meeting itself was somewhat anticlimactic. Frosch, Frutkin, Dick Barnes (of the International Office), Yardley, Schneider, Andy Stofan (from the Office of Space Sciences), Bonita Sidwell (from the Administrator's Office), and I met with Gibson and Mellors of ESA. Gibson appeared somewhat apologetic about all the commotion he had caused—apparently he was under considerable pressure to make a strong stand before NASA. His member delegations were extremely upset about Spacelab cost overruns and were raising every issue that had been bothering them from the start of the program. Issues which did not seem so important when the program was at 95 percent of the ceiling were considered serious problems as costs approached 120 percent.

The meeting began with discussion of NASA's insistence on a second Mission Specialist for Spacelab 1. Gibson reluctantly agreed that the case had been made for Spacelab 1, but he was concerned about the precedent established. Also discussed was the interference problem discovered on the Tracking and Data Relay Satellite, which would require redesign and considerable delay of the Spacelab 1 mission. Finally, the thrust of the Gibson letter came under consideration. NASA made it clear that it felt most of the charges were without substance and that the critical issue was what could be done to convince Europe to agree to the proposed barter. It was decided that NASA would send a team to the next Spacelab Programme Board meeting to present its case. As reported in chapter 7, this effort proved unsuccessful.

Frosch and Gibson next met on October 7 for a formal review of the overall program (fig. 88). The meeting resulted in the following assignments to the Spacelab Program Directors: prepare a post-delivery change control plan, review an ESA proposal for operational support, and continue the analysis of European source spares. It was pointed out that the Spacelab 1 mission was now targeted for June 1981 and Spacelab 2 for December 1981. ESA was concerned about these slips because of commitments to its member states to terminate European funding of sustaining engineering by the end of 1981. The final discussion points on Spacelab concerned the approach to be taken in follow-on procurement assuming rejection of the barter by the Programme Board and questions about the possibility of ESA Mission Specialists. After discussion related to future Space Transportation System aspects, the agency heads turned to the solar polar mission, the space telescope, and remote sensing.

Figure 88. NASA participants in the October 1978 meeting between the ESA Director General and the NASA Administrator in Paris are, left to right, Kenny Kleinknecht, Jim Morrison, William Lucas, Philip Culbertson, Robert Frosch, Norman Terrell, John Sakss, Douglas Lord, and Jack Lee.

Gibson and Frosch met on March 29, 1979 for an informal session to "take the pulse of Spacelab as it nears its final development stage." The key topics at this meeting were: the continuing deterioration of ESA/NASA relationships, differing interpretations of the Memorandum of Understanding, a Spacelab improvement program, and ESA's cost-to-completion limitation. On May 7, Frosch wrote to Gibson proposing the following actions: (1) establish a joint group to review proposed reduction actions by ESA with respect to its cost-to-completion limitation (Jim Harrington would head the NASA team), (2) establish a group to determine whether racks and pallets proposed by the U.S. substantially duplicate the first Spacelab (Dick Smith, Deputy Associate Administrator for Space Transportation Systems, would head the NASA contingent), and (3) establish a group to define a follow-on development program (Bob Lohman would co-chair this group for NASA). In his letter, Frosch also referred to ongoing efforts to reduce ERNO's follow-on procurement proposal to an acceptable level and called for the NASA Office of Space Sciences to resume dialogue with ESA on joint utilization of Spacelab. Gibson responded affirmatively to the Frosch letter and the three new groups began their work. As could be expected, each group was given a suitable acronym. The first group would be called the Risk Assessment Working Group (RAWG) since it was to assess the risk associated with various program cost reductions. Project Manager Pfeiffer would lead the ESA team. The second group was named the Duplication Avoidance Working Group (DAWG), and would investigate ESA charges of duplication of European Spacelab efforts by U.S. organizations. ESA Programme Director Michel Bignier was named to co-chair the group for ESA. Almost immediately, it was necessary to name a new NASA co-chairman because Dick Smith got caught up in a circus atmosphere of activity related to the pending atmospheric reentry of the Skylab assembly left in orbit since 1974. Phil Culbertson was named to replace Smith. The third group was named the Follow-on Development Content (FOCO) Working Group, whose activities are discussed in chapter 7.

The agency heads next met to review the Spacelab program in Paris on February 14, 1980. It was noted that considerable progress had been made by both ESA and NASA; however, the date for the first Spacelab flight had by now slipped to December 1982. Both sides were delighted that the follow-on procurement contract had been signed and were hoping that a parallel contract on the IPS could be signed by April 30, contingent on a successful CDR-A. The joint working groups on risk assessment, duplication avoidance, and follow-on development presented their reports, and the first two groups were dissolved. Future questions relating to Spacelab duplication would be handled by the Joint Spacelab Working Group. After disposing of these critical issues, Frosch and Gibson discussed planning for the Spacelab 1 payload and Spacelab utilization, then turned to the subjects of remote sensing, Earth-oriented research, and a workshop on the economics of space programs.

Before the next meeting, there would be a change on ESA's side of the table. After many years in key administrative positions at ESRO and after several years as the first Director General of ESA, Roy Gibson decided it was time to pursue a new career. Erik Quistgaard, a Dane and former key official of the VOLVO company, was selected to take his place. Quistgaard came to Washington on October 6, 1980 to meet Frosch and to review the progress on Spacelab and other joint ESA/NASA undertakings. He told Frosch that the engineering model was being prepared for the acceptance review and subsequent delivery to KSC and that the flight unit was scheduled for delivery by September 1981. Meanwhile, on the NASA side, the Spacelab 1 mission was now scheduled for June 1983. It seemed as if the slippages were never going to stop.

Although a post-delivery change control agreement was ready for signature, ESA continued to press for a maximum limit of funding for its post-delivery support. ESA was trying valiantly to honor its 140 percent ceiling, but NASA refused to let ESA off the hook for what was considered to be the latter's responsibility. Other difficult Spacelab-related subjects discussed at this meeting were questions about IPS performance and the issue of when the ESA biomedical experiment known as SLED, recently descoped from the Spacelab 1 payload, could be rescheduled for flight. ESA presented a rather bleak picture as far as its plans for Spacelab utilization following Spacelab 1, but did report that Phase B studies on follow-on development had been approved. The remainder of the meeting was devoted to remote sensing;

cooperative science programs including the International Solar-Polar Mission (ISPM), GIOTTO (an ESA spacecraft planned to intercept Halley's comet), and the space telescope; coordination of future STS studies; and NASA's desire for more reciprocity in U.S. and European flight opportunities. A red flag was raised in the ISPM discussion because NASA had been forced to descope this project due to budget shortages and the European science community was worried about the health of the project.

By their next meeting on March 9, 1981, Quistgaard and Frosch were grappling with the budgetary constraints which forced NASA to reduce its participation in the International Solar-Polar Mission. After many years of cooperative planning by the two agencies, this was a tremendous blow to ESA and to the cause of international space cooperation. The meeting was focused almost entirely on this controversial topic, no minutes were signed, and apparently all other programs, including Spacelab, took a back seat.

On June 17, 1982, the agency heads met again in Paris, this time with a new face on NASA's side of the table. James E. Beggs had replaced Dr. Frosch as the NASA Administrator. Beggs was no stranger to NASA, having served as an Associate Administrator at NASA Headquarters before serving in other high-level administration positions including Undersecretary in the Department of Transportation.

By this time, the focus of the DG/A meeting had changed considerably. Emphasis at this meeting was first and foremost on future plans for NASA/ESA cooperation. Agreement was reached on a set of "General Principles for NASA/ESA Cooperative Agreements," procedures were established for a regular exchange of views on future programs in space science and applications, and information was exchanged on each side's activities directed toward the Space Station and platforms (e.g., EURECA, the European retrievable carrier). Exchanges continued in the area of remote sensing. Spacelab topics were relegated to the level of status reports on developmental activities, the Spacelab 1 payload and mission preparations, and the launch date. Except for some problems with the launch date, no serious concerns were expressed on the Spacelab program. How times had changed.

RISK ASSESSMENT WORKING GROUP

Established following the March 29, 1979 DG/A meeting, this group had a very interesting assignment. Each side had a different understanding of the meaning of the ESA program commitment. ESA considered that its commitments would be fulfilled at the point of delivery of the Spacelab flight units to KSC and at successful completion of the IPS/Spacelab compatibility tests in the U.S., with the exception of limited and already defined sustaining engineering support. NASA interpreted the Memorandum of Understanding as requiring a more substantial commitment of ESA beyond the flight unit deliveries. In order to meet specified performance (make-work changes), NASA considered that the responsibility for funding and implementation rested with the developer (ESA) until the completion of flight verification (the

Spacelab 1 and 2 missions). Regarding interface definition and changes to the Shuttle/Spacelab interfaces, NASA interpreted that each party should meet its responsibilities by funding changes to its side of the interface. The assignment of the working group was to define the risk and corresponding cost to NASA if ESA's proposed transfer of responsibility was accepted. The team of Bob Pfeiffer, Chris Reinhold, Frank Longhurst, and Gordon Bolton of ESA, and Jim Harrington, John Thomas (MSFC), Jerry Richardson (MSFC), Frank Bryan (KSC), and John O'Loughlin (JSC) of NASA held three meetings in 1979 to investigate these questions and prepare its report, which it completed in December and presented to the agency heads at their February 1980 meeting.

ESA's motivation to obtain a cutoff date for its commitment was obvious. It had been given a cost ceiling for the program which had been increased twice. The Spacelab Programme Board was at the end of its patience and was pushing ESA to force NASA to accept a transfer of responsibility that would end the additional cost increases to ESA.

The working group selected September 30, 1979 as the date for transition of responsibility from ESA to NASA for the purpose of its assessment. It then attempted to define changes that would have to be made to provide system performance and to meet interface changes between the Spacelab and the Shuttle or facilities. It recognized that some of these changes might be make-work changes and that others could be caused by new requirements. It also divided the changes into those to be made prior to delivery and those to be made after delivery through the completion of the Spacelab 2 mission. In order to define these changes, the group considered data from several sources: the experience to date with the engineering model and the IPS, the status of the Spacelab/Orbiter interface and the design status of each system, and the experience gained from changes and costs subsequent to the delivery of the Skylab Orbital Workshop to KSC.

The result of this analysis was an estimate that $21.6 million would be required prior to delivery and $22.0 million after delivery. Of these amounts, ESA's planned contributions totaled $19.3 million and $3.3 million, respectively. The cost risk to NASA therefore was $2.3 million to cover changes prior to delivery and $18.7 million for changes after delivery. In assessing post-delivery sustaining engineering provisions, the group found that proposed contributions covered the total program requirements and there would be no cost impact to NASA.

When the results were presented to the agency heads, they agreed that except for IPS, ESA would be responsible for correction of all obvious and hidden deficiencies necessary to meet the Spacelab specifications and Interface Control Documents as they existed on September 30, 1979. In the case of IPS, ESA would be responsible for compliance with the specifications and the ICD as agreed upon at successful completion of the IPS CDR-A. These responsibilities would continue through the first flight of a component, but no later than completion of the second Spacelab flight. NASA would be responsible for compliance with any new or modified specifications and ICDs after these cutoff points. The Risk Assessment Working Group had tackled a very difficult question and apparently had provided for a satisfactory solution.

DUPLICATION AVOIDANCE WORKING GROUP

The problems that resulted in establishment of this working group were longstanding. As would be expected, ESA and NASA were aligned solidly on each side of the issue—ESA attempting to safeguard contract opportunities for its consortium on the development of anything remotely akin to the Spacelab concept and NASA interpreting the Memorandum of Understanding in its broadest sense in order to develop flight and ground hardware for its programs at the lowest cost possible. Thus, at the extreme, ESA would insist that any payload carrier that could be mounted in the Shuttle cargo bay duplicated the Spacelab, and NASA would insist that unless a carrier was identical to the ESA Spacelab flight hardware design, it could be developed and manufactured in the U.S.

The critical wording in the Memorandum of Understanding to be variously interpreted was, "NASA will refrain from separate and independent development of any Spacelab substantially duplicating the design and capability of the first Spacelab unless ESA fails to produce such Spacelabs, components, and spares in accordance with agreed specifications and schedules and at reasonable prices to be agreed."

Mention was made earlier of the controversy surrounding the development of the Instrument Pointing System in Europe and several competing systems in the U.S. A second controversy arose over the pallets in Europe and the MPESS at MSFC. Things really came to a head, however, when ESA discovered that Ames Research Center was using European drawings to fabricate Spacelab racks, and it appeared that the Department of Defense was going to build its own pallet structure for mounting experiments in the Shuttle cargo bay.

I attempted to blunt the Ames fiasco by writing to Bignier on August 17, 1978 to assure him there was no intent to build racks in competition with the European flight racks. I tried to explain that these were really "rack integration aids" to be used in the Ames life sciences program for ground processing activities (in lieu of using flight racks). European contractors would be given the opportunity to bid on such integration aids. Bignier's reply was less than conciliatory. He would agree to the development of such hardware in the U.S. only if it could be shown to be more cost-effective.

At the January 16-17, 1979 Joint Spacelab Working Group meeting, Robert Mory of ESA (formerly Spacelab representative at MSFC, but now a member of Bignier's Headquarters staff) presented the results of European industrial proposals to manufacture the "rack integration aids." I then presented a NASA cost breakdown for comparison showing an advantage of $71 000 for the racks NASA could build inhouse, due almost entirely to the much lower transportation costs. We planned to move forward with the inhouse build. ESA was very upset about this decision, insisting that the MOU required prices to be "reasonable," not competitive. I then reaffirmed my position that these racks did not fall under the terms of the MOU because similar integration aids were not being delivered to NASA under the ESA development program.

On January 25, 1979, Bignier offered another proposal. ERNO had now reduced the total cost to $432 000 as compared with Ames' bid of $399 000. ESA considered ERNO's bid to be reasonable and competitive and one which should be accepted by NASA. This time I replied to Bignier that NASA would procure the rack aids under the terms of the MOU if ESA would develop and deliver the first units (one single and one double rack each) free to NASA, with subsequent units at the price proposed by ERNO. I stated that this was not to be considered a precedent for future cases and that an understanding of the boundaries of the MOU provision on NASA development of items needed to be established. This was the situation at the time of the DG/A decision to establish a special working group. It was no wonder that Bignier was seeking a higher level of arbitration.

In addition to Culbertson as its co-chairman, NASA designated Andy Stofan, Ken Pedersen, Jack Lee (MSFC), and me to its team. Stofan would represent Space Sciences and Pedersen was now Director of the International Affairs Office. ESA selected Emiliani, Reinhold, Jean-Louis Collette, and Jan Bijvoet to support Bignier. Meetings were held on July 18–19, October 17, and December 6, to discuss five specific cases: rack integration aids, reflight of OFT pallets, the DOD sortie support system, pointing systems, and the T-structure (MPESS).

By the time of our report to the Director General and Administrator on February 14, 1980, the working group had made substantial progress, but had not resolved all the issues. However, we had reached agreement in at least two areas. On the OFT pallets, we agreed that reflight could be considered based on postflight analysis and inspection, refurbishment to be funded by NASA, and ESA concurrence to be obtained on flightworthiness. On the pointing system, we agreed that IPS would be the primary Spacelab pointing system, with ASPS as backup.

The rack integration aid controversy was considered closed without agreement. NASA was proceeding with the development at Ames and ESA had given up the fight. In the meantime, this situation had been thoroughly confused by Ames' mishandling of Aeritalia drawings. There was considerable bad feeling on both sides about this subject, but the NASA procedures for proper handling of European Spacelab drawings had been reemphasized and it appeared they would be respected henceforth.

The most important recommendation of the Duplication Avoidance Working Group was to establish the following guidelines and procedures for future cases:

(1) New NASA requirements related to Spacelab would be communicated to ESA and discussed by JSLWG.
(2) JSLWG would attempt to reach agreement on "substantial duplication" of a proposed system or its components.
(3) Criteria to be used would be capabilities, design, interfaces, and possibility of substitution by Spacelab hardware with minor modification, if necessary.
(4) If JSLWG determined "substantial duplication," the MOU and Intergovernmental Agreement provisions would apply.
(5) If JSLWG determined "no substantial duplication," ESA could make pro-

posals for development, with or without European funding. NASA would treat European and U.S. proposals on an equal basis.
(6) If JSLWG cannot agree, the ESA Director General and NASA Administrator would arbitrate.

The Director General and Administrator accepted these recommendations and then turned to the unresolved issues: how to handle new proposals for ground-type equipment, the DOD sortie support system, and the T-structure. On the ground-type equipment, ESA accepted the NASA position that all simulators, integration aids, and mockups are not subject to the "substantial duplication" clause provided that NASA does not misuse European manufacturing drawings. On the other items it was agreed that there would be further exchanges between the agencies and with the Air Force, as necessary.

Although the working group was dissolved at this time, a final meeting was held on April 3, 1980, when a modified team consisting of Culbertson, myself, Dr. Pellerin (now deputy to Jesse Moore in the Spacelab Payload Office), Jim Zimmerman, and Lyn Wigbels of NASA (the latter two representing the International Office), and Bignier, Mory, and Mellors of ESA met to discuss the sortie support system and the T-structure.

Controversy about the DOD sortie support system had been festering for many months. It came to light in early 1979 when it appeared that General Electric was on the inside track to develop a pallet for DOD use. This carrier was proposed to provide a simplified platform for DOD experiments in the Shuttle comparable to that provided for secondary test payloads which had been carried on a space-available basis on DOD expendable launch vehicles for many years. During the past year, ESA, NASA, the Air Force, and the State Department had discussed the possible use of ESA Spacelab hardware to help meet Air Force needs. Finally, on March 6, 1980, Robert Herman, Air Force Assistant Secretary for Research, Development, and Logistics, agreed to the necessary wording in the RFP to ensure that European Spacelab contractors would receive consideration as subcontractors to any U.S. bidders for the sortie support system.

At our April 3 meeting, there were still open questions with respect to the sortie support system, but nothing that would preclude European participation in the program. As so often happens in situations like this, after all the commotion, nothing materialized in the end because the Air Force canceled its plans for the new system.

The T-structure, also referred to as the MPESS, was a modular structure under development by Teledyne-Brown for MSFC to carry small instruments in the cargo bay. Its specific use was for the OSTA-2 payload, but it was expected to be used repeatedly. At the April 3 meeting, Bignier accepted NASA's position that the T-structure did not "substantially duplicate" any item being produced in the ESA Spacelab program, according to the criteria recommended by the working group and accepted by the agency heads. Although ESA had secured counter proposals from British Aerospace and MBB, all parties were now ready to accept use of the Teledyne-Brown structure. Culbertson agreed that in the future where new requirements were identified, ESA would be given the opportunity to make a proposal.

One other controversial area of duplication concerned the ground-type nonflight equipment. At the June 12 Joint Spacelab Working Group meeting, such equipment was defined as follows: (a) simulators for training, procedure development, and verification and (b) integration aids for tooling, packaging design verification, and transportation of payload equipment. It was then agreed that "the above equipment would be candidates for exception to the criteria for determining substantial duplications as long as these items, or their components, are only ground models of Spacelab flight or Engineering Model hardware and are not designed and manufactured according to detailed European Spacelab drawings." With this final compromise, the issue of "substantial duplication" finally was put to rest. It had been the source of considerable anguish and resentment on both sides.

POST-DELIVERY CHANGE CONTROL

Another issue requiring a long negotiation was the establishment of procedures for post-delivery change control. What would be ESA's role during this period, and how would changes required in the first unit be implemented in follow-on production hardware? These and other plans were first presented at the DG/A meeting in October 1977 and were accepted in principle at that time. At the next Joint Spacelab Working Group meeting in November, ESA presented its counter proposal. One of the most difficult questions pertained to the time criticality of a change and whether it should be returned to the European vendor. Another problem was where the current configuration data would be maintained, on-site in the U.S. or in Europe. ESA was anxious to retain design authority in Europe to again safeguard the opportunity for future contracts in Europe. NASA was just as interested in maintaining control with its integration contractor to ensure expeditious changes as needed and to protect launch schedules.

By April 1978, ESA Level II made a new proposal: each side would be free to modify the hardware under its own control, each side would fund the activities on its own side, and each side would not automatically accept modifications requested by the other side, but decide on a case-by-case basis. Problems would be reported to the Program Directors (Level I). NASA felt that this proposal was not in accordance with the previous agreement that ESA would implement and fund all make-work changes. It was agreed that Level II would go back to the drawing board and attempt to resolve the remaining issues.

Again in November, the JSLWG discussed another Level II proposal. This time both sides were in agreement except for the issue of reciprocal concurrence on proposed changes. This controversy was resolved and an agreed-upon plan was submitted to Bignier and me in January 1979. Discussions on the change control plan continued for the next several meetings of the Joint Spacelab Working Group, but it was obvious that the increase in the funding ceiling for ESA from 120 to 140 percent was receiving primary attention, and ESA was not in a mood to sign any agreement with NASA that could result in increased funding obligations.

By June 10, 1980, Level II (Pfeiffer and Lee) presented its latest version of the plan to Level I (Bignier and me). This plan included a ceiling amount of $7.3 million for all ESA make-work changes, the number derived from the report of the Risk Assessment Working Group. Again, I took the position that NASA could not accept any such ceiling and that the matter would have to be presented to the agency heads. I considered the instruction of the Programme Board to ESA in this regard as contradictory to the terms of the MOU, which required ESA sustaining engineering support through the second Spacelab flight.

At their meeting on October 6 Quistgaard and Frosch agreed with the position I had taken that the post-delivery change control agreement would not include a ceiling figure for ESA-funded changes. If it became apparent that ESA funds were insufficient for completion of necessary changes, then NASA and ESA would determine what steps would be taken vis-á-vis their respective funding bodies. With this agreement, the way was paved for Bignier and me to sign the agreement, which we did at the next meeting of the Joint Spacelab Working Group on November 3 and 4. Both of us expressed satisfaction at having finally reached agreement. Perhaps relief would have been a better word.

OPERATIONAL COST CONCERNS

The Cost Reduction Alternatives Study, conducted in 1975 in conjunction with the 1977 budget preparation, did not lay to rest agency concerns about potential costs to operate the Spacelab. During the NASA Administrator's review in late 1979 of the 1981 budget for the Office of Space Sciences, the Spacelab utilization costs were presented in a consolidated manner that raised serious concern about their magnitude. In particular, the Administrator reacted that the costs were not in keeping with the concept of a walk-on laboratory. As a result, he called for formation of a Spacelab Utilization Review Committee to analyze the costs and to make recommendations for making the Spacelab a cost-effective vehicle for conducting science missions. Lawrence J. Ross of the Lewis Research Center was appointed to chair the committee, whose members were Edwin T. Muckley and John J. Nieberding (Lewis), Leonard Arnowitz (Goddard), Carlos C. Hagood and John W. Thomas (MSFC), Creighton A. Terhune (KSC), Loren W. Acton (Lockheed Payload Specialist), John R. Carruthers (Headquarters), and John A. Rummel (JSC).

After several months of study, including exchange of materials and visits with the ESA Spacelab-Lessons Learned Committee chaired by Dr. Shapland, the committee made its report to the Administrator on May 5, 1980. In its overview, the committee concluded the following:

(1) Spacelab is much more complex than originally envisioned.
(2) Spacelab generally meets the technical requirements of users.

(3) Costs for integrating experiments were found to be consistent with the task required and not likely to be substantially reduced in the future.
(4) Spacelab is a valuable resource in the NASA inventory and unique in many respects.
(5) Software is well-managed and developed in a technically sound manner.
(6) The longer the time between selection of instruments and flight, the greater the cost.
(7) Some management shortcomings can and should be remedied.

The committee's primary recommendations were as follows:

(1) Simplify NASA Headquarters and center-level management for Spacelab and identify a single individual responsible for Spacelab mission conduct.
(2) Ensure the existence of a single, authoritative mission model.
(3) Do not start the mission integration process before the payload complement has reached a reasonable degree of maturity.
(4) Establish a mission complement which has payloads grouped according to common flight constraints.
(5) Establish a meaningful reflight policy and foster experiments of opportunity.
(6) Do not attempt to optimize the use of all Spacelab flight resources.
(7) Encourage the autonomy of experiment hardware when it will save costs to NASA.
(8) Substantially reduce documentation.
(9) In conducting the Announcement of Opportunity, minimize the interval between experiment selection and flight.

It is not clear that the Administrator made any specific changes as a result of the Ross committee report, and the perception that Spacelab operations costs were too high persisted in the minds of NASA upper management. By July 7, 1982, a new cost review was presented to the Administrator by Mike Sander (now successor to Jesse Moore as Director of the Spacelab Flight Division within the recombined Office of Science and Applications), and Jim Harrington (Director of the Spacelab Division within the Office of Space Transportation Operations). Their presentation focused on three areas of Spacelab costs: operations, mission management, and instrument development. They noted how the perception of the Spacelab concept had changed during the past several years. Instead of carrying cheap ground laboratory equipment, the instruments on board now required major investments of development effort. Instead of presenting simple, easy-to-use interfaces, the Spacelab now required 2-3 years of requirements definition with formal processes and little emphasis on reflight. Instead of flying often, there were limited opportunities. Instead of not optimizing the use of resources, every resource was being used to the maximum. Instead of taking risks and accepting failures, the present procedure was to be very safe and assure instrument reliability. And instead of $10 million per Shuttle launch, the cost now was more like $100 million per launch. Sander and Harrington pointed out that the Spacelab program was at the beginning of its learning process in so far as operations costs were concerned, and further study was necessary. They noted that many significant missions and payloads were planned through the next decade and that the opportunity should be taken over the next several months to examine the entire program in detail and to search for means to reduce costs which could be reflected in the 1985 budget.

The resulting study was called the Spacelab Mission Implementation Cost Assessment (SMICA), which, although started in August 1982, was not completed until the end of 1984. Under the joint leadership of Harrington and Sander, a steering committee was established to review progress reports from the SMICA study team and to provide overall direction. The general approach taken by the study team was based on the belief that operational costs for the early Spacelab missions did not truly reflect the costs that could be expected for "typical" Spacelab missions of the future. First, the early missions had been learning experiences for the Spacelab and included verification flight test objectives. Second, the missions had been subject to unplanned delays of the carrier vehicles (Shuttle and Spacelab). Furthermore, Shuttle and Spacelab development problems in some cases had spilled over into the experiment development as loads were increased or as changes were made in the basic design or performance characteristics.

Spacelab 6, a mission sufficiently far in the future to be responsive to changes in operational procedures, but near enough at hand to be defined in some detail, was selected as the typical mission for analysis. The apparent cost for this mission would be on the order of $110 million—$66 million for experiment development and $44 million for mission integration and operations cost. With this baseline, the team analyzed 147 proposed steps which could be taken to reduce the costs, ending up with a postulated savings of $18 million, a reduction of some 16 percent. Cost savings were achieved in six areas: experiment development, new mission scenario, Payload Operations Control Center, KSC standard flow, analytical integration, and documentation. Unlike previous studies of this kind, however, the SMICA study seemed to go a step beyond what might have been expected: it developed implementation plans for its recommendations and in many cases had implemented some of the cost-saving changes within the program by the time the study was completed. The key principle involved in most of the recommendations was to recognize that time is equivalent to manpower and cost, so the most significant savings would be accomplished by reducing the duration of the cycles in every phase of planning and preparing for a given mission. The most significant hardware change recommended was to develop a new and more efficient Payload Operations Control Center at MSFC and to phase out the existing POCC at JSC. It would be interesting to see whether this and the other recommended changes would significantly impact the cost of Spacelab operations.

One final input from the SMICA study was the analysis of reflight missions. The study concluded that a repeat mission could be flown with a reduction of 86.4 to 90.5 percent of the mission operation costs, depending on the amount of deintegration and reintegration needed. Clearly, this would be an approach worthy of serious consideration for future mission planners.

ORGANIZATIONAL AND PERSONNEL CHANGES

As the time neared for Shuttle operations, a major change was made in the KSC organization. In early 1979, the Space Transportation System Projects Office and the Space Vehicle Operations Directorate were each divided into separate management organizations for the Shuttle and for Shuttle payloads. The STS Projects Office managed by Dr. R. H. Gray was divided into a Shuttle Projects Office under Gray and a Cargo Projects Office under John Neilon. The KSC Spacelab Project Office would be included in the latter organization and would continue its planning activities.

Similarly, the Space Vehicle Operations Directorate under Walter Kapryan was divided into a Shuttle Operations Directorate under Kapryan and a Cargo Operations Directorate under George F. Page. Isom (Ike) Rigell would be Page's deputy and also Acting Director of Spacelab Operations, responsible for hands-on activities with the Spacelab. With these changes, Neilon and Rigell would become the principal leaders and points of contact within the Spacelab program to assure Spacelab's readiness for upcoming missions. In addition to these changes within KSC, Alex Madyda assumed his duties as the MSFC Resident Spacelab Program Support Representative at KSC.

Major changes also took place at NASA Headquarters about the same time in the organization for planning the Spacelab payloads. Jesse Moore was named to head a new Spacelab Mission Integration Division within the Office of Space Sciences that included the groups which had been working on Spacelab payloads in both the Office of Space Sciences and the Office of Applications. Dr. Charles Pellerin was his deputy, Bob Kennedy headed the science branch, Bobby Noblitt the applications branch, and Bob Benson the Level IV integration planning. This organization was later changed in the 1981 move that consolidated the Offices of Space Science and Applications. At that time Jesse Moore accepted a new assignment as head of the Earth and Planetary Exploration Division, and Mike Sander replaced him as head of what was then renamed the Spacelab Flight Division. A related change took place in the Payload Support Office at MSFC when in 1981 O. C. Jean left the agency to form his own consulting firm and was replaced by Dr. Jim Downey, a long-time science manager at Marshall.

By mid-1979 Kenny Kleinknecht was recalled from his assignment as senior NASA advisor to Bignier in Paris. Yardley, concerned about continuing problems plaguing the Shuttle program (particularly delays in attaching the thermal tiles to the Orbiter) selected his old friend Kleinknecht to become the JSC Orbiter Manager at KSC. There would be no replacement from NASA to serve as advisor to the Spacelab Programme Director in Paris.

Continuing problems with Shuttle development resulted in a major reorganization at NASA Headquarters in 1980, when Yardley was divested of all his responsibilities except the Shuttle. The new Office of Space Transportation Systems, headed by Yardley, would represent the engineering base for putting the STS in place, and an Office of Space Transportation Operations would provide the operating base

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for planning and conducting STS operations. The Spacelab program would be managed as a division of the Operations Office, which in turn would be headed by Glynn Lunney as Acting Associate Administrator until Dr. Stanley Weiss, formerly of Lockheed, would join NASA as its permanent head.

Other changes in the round of musical chairs within the NASA Spacelab organization included John Thomas replacing Luther Powell (now working on power module planning) as Deputy Program Manager at MSFC and Ray Tanner taking Thomas' job as Chief Engineer. Leo Hall then left the test lab at MSFC to take over from Bob Spencer the leadership of the NASA resident office at ERNO. A significant loss to the program was the retirement of Walt Kennedy who had led the logistics planning effort at MSFC from 1974 until 1980. In the meantime, mention needs to be made of the increasingly important role in the program played by John O'Loughlin at JSC as more and more Spacelab support activities became focused at this key center for STS operations.

Although it is impossible to report on all the personnel changes that occurred on the ESA side, some need to be mentioned because of their particular significance to NASA. Jan Bijvoet replaced Robert Mory as the ESA resident representative at MSFC. Bijvoet, a Dutchman, soon became very much at home in Huntsville, transfering his sailing skills from the North Sea to the Tennessee River with ease. After several years of providing effective representation for ESA at MSFC, Bijvoet would return to Europe to join Mory as a member of Bignier's staff. Meanwhile, the ESA resident team at Bremen, established under the administrative leadership of Charles Cannon, looked to Peter Wolf for its technical leadership during the early phases of testing at ERNO and later to Alan Thirkettle as preparation of the first flight unit got under way. The move of Thirkettle, formerly structural engineer of the ESA project team, to the resident office at ERNO was also of major significance. Thirkettle would become almost an integral part of the Spacelab flight unit, remaining with it through its final checkout, transport to KSC, and preparation for its first launch.

It is also interesting to observe the change in Bignier's role at ESA during these years. Initially he was responsible only for the development of Spacelab and the function of the SPICE organization established by Deloffre. Then, as the ESA portion of the first Spacelab payload was defined, he was given the responsibility for this facet of the program as well. Eventually his office was renamed the Space Transportation System Office, and he was also given responsibility for the Ariane expendable launch vehicle and other elements of the ESA program including the unmanned retrievable free-flier, EURECA. Thus, Bignier's role in the ESA hierarchy became increasingly important, whereas the responsibility of the NASA Spacelab Program Director remained relatively unchanged.

Personal Reflections

It has been said that the relationship between Dornier and MBB concerning the instrument pointing system was strained from the outset. Dornier was attempting to develop, under a fixed-price contract, a very complicated pointing system that would challenge the state of the art. Meanwhile, MBB was assigned 60 percent of the contractual effort. The arrangement was doomed from the beginning. Furthermore, MBB was a much larger conglomerate, with considerable political clout in southern Germany. Dornier, traditionally a family-owned company (although more recently taken over by Daimler Benz) of limited means, was at a distinct disadvantage in negotiating with its bigger partner in Munich. When technical and funding problems multiplied, their relationship became increasingly combative. The partnership was finally dissolved at the time of the redesign of the pointing system.

One technical requirement for the IPS—the man-motion disturbance—has always struck me as unreasonable. Why was it necessary for the IPS to overcome the motion imparted by an astronaut performing a wall pushoff? Couldn't the crew be informed when the IPS was in operation, at least when critical measurements were being made with the optical instruments requiring precise pointing, so that they could remain quiet for these periods during the missions? Perhaps it was naive of me to think that crew timelining could be used to simplify such difficult performance specifications. Experience with the Spacelab 2 mission indicated that these disturbances were more severe than expected, although the motions did damp out quickly.

Trips to Dornier were always interesting and often quite unpredictable because of the weather conditions in the Alps or around Lake Constance. Sometimes, rather than driving, we flew from Zurich to Freidrichshafen using a shuttle service provided by a small airline company. When the weather was good, this was a delightful flight, but when it was bad, I was never sure whether it was better to be bumping through the rain clouds in a small plane or brave the unfamiliar fog-shrouded roads and ferry-boat ride.

Although the international Spacelab program was conducted in English, there were times when local languages could not be avoided at the working level. Occasionally, different languages surfaced at the management level when unique problems were being discussed. One of these situations occurred in the case of the IPS when the "spannring" broke during vibration testing, apparently due to reinforcement by means of an additional "stutzring." Certainly no English translation could result in adequate replacements for these words. And when spoken by a native German, they took on added character.

My final visit to Dornier before leaving the program was in October 1980. At that time it appeared that the IPS program, having overcome its initial problems, was proceeding quite well. The test setup and hardware demonstration in the clean room were most impressive. The major problems at the time appeared to be twofold, financial and system performance. As it turned out, these problems were far more serious than they appeared at the time, and within a few months, the increasing loads from the Shuttle provided the straw that broke the camel's back.

Following the IPS redesign, both NASA and ESA placed added emphasis on program oversight. For NASA, the assignment of Gene Compton as its full-time liaison representative at Dornier was the most important action taken. Gene, who had been following the program for MSFC from its inception and who had performed many of the NASA analyses related to its performance, was uniquely qualified to fill this role. He also had the kind of personality that could open doors at Dornier without offending the ESA management team. His assignment would stretch out for a much longer period than first anticipated, but Gene would stick with it to the end, and his contributions would prove to be instrumental in the final delivery of IPS flight hardware and the supporting systems and software. At the end of his IPS assignment, Gene would move on to Turin to work on the cooperative Tether Satellite Program.

Although the McDonnell Douglas Technical Services Company would seem to have been a new company established for the Spacelab integration contract, its roots went back to the 1960s when McDonnell (St. Louis) lost its preeminent role in the Mercury and Gemini programs to North American (Rockwell), which had been awarded the Apollo spacecraft contract. McDonnell was anxious to retain some role in the manned spacecraft business and so set up a Houston Aerospace Division to provide support for the Apollo mission simulations. This team continued to work on various JSC programs until 1973, when it won a competition to provide support to the Shuttle Program Office. The corporate structure for MDTSCO had been set up earlier to provide assistance to the Japanese in the development of Douglas missiles, and although that effort had been completed, the company had not been phased out of existence. The decision was then made to merge the corporation that did not have a job with the division that needed a corporate structure, and the MDTSCO Houston Aerospace Division was the result.

On the west coast, the Douglas half of McDonnell Douglas had a similar history. After playing a key role in the Skylab program and then serving as prime contractor for the Air Force Manned Orbiting Laboratory until its cancellation, the Huntington Beach group hoped to obtain a major role in the proposed Space Station effort. The cancellation of these plans and the role of this group in providing early support to ERNO is traced in earlier chapters.

When the Spacelab integration effort was opened for competition, McDonnell Douglas found itself in a very strong position, with experienced personnel ready to undertake the new responsibilities. When it won the competition in 1977, the Spacelab Integration Division of McDonnell Douglas Technical Services Company was established in Huntsville, with a subordinate team to provide hands-on support at KSC. In addition to the two portions of the Spacelab contract at MSFC and KSC, MDTSCO won a competition at KSC in 1979 for the Interim Cargo Integration Operation (ICIO) contract, which called for the operation of the Vertical Processing

Facility and the CITE stand in the Operations and Checkout Building. The two portions of MDTSCO were then redesignated as the Huntsville and Kennedy Operations Divisions. Subsequently, MDTSCO won competitions held at JSC for operational support to the Shuttle program and at KSC for the operation of the Air Force Shuttle Payload Integration Facility. So, from a modest start, MDTSCO has become a very successful service organization indeed.

When the MDTSCO group was set up in Huntsville, first for the proposal effort and later for implementation of the Spacelab integration contract, Ed Bonnett, formerly of the Delta launch vehicle program, was General Manager, with Dave Wensley, newly returned from assisting ERNO, as his deputy. Their first challenge was to obtain good people. Fortunately, some recruits were available from the consultant team at ERNO, others from the Delta program, and others with Skylab and Saturn experience within the parent corporation or who had left the company during the lean years and were anxious to return to the McDonnell Douglas family. Most of the hiring, however, was from other sources, and this led to some of the problems described earlier. In some cases, however, MDTSCO was surprisingly successful. For example, in response to a newspaper ad, the head of the Brown Engineering thermal analysis group walked into the MDTSCO office and said he had three people working for him who might be interested in jobs. After accepting three application forms, he commented that he might be interested, too. He was immediately given a fourth form and was soon hired along with the other three.

Through the years of Spacelab development and early operations, no element of the program played a more vital role than did MDTSCO as the NASA integration contractor. In bringing together all the skills and resources necessary to accomplish its varied engineering and operational tasks and in overcoming the many problems, Jake Jacobsen (who replaced Bonnett) and Dale Steffey, who provided the overall leadership at Huntsville, and George Faenza and Ed Scully, who directed the efforts at KSC, deserve special recognition and appreciation.

In outfitting the Software Development Facility, MDTSCO encountered several challenges in obtaining hardware from European Spacelab contractors. One story relates to the need for a remote control capability for the CIMSA computer. MDTSCO managers went to Europe to negotiate with CIMSA, working through ERNO, the prime contractor, and MATRA, the data system contractor. CIMSA was in the process of marketing its computer for fairly wide applications, but insisted that MDTSCO would have to pay for all the development costs of the added capability needed for the Software Development Facility. MDTSCO took the position that CIMSA should pay the development costs so as to provide added capability for other users and sell it to MDTSCO as a catalog item. After much negotiation between MDTSCO and CIMSA, with technical and legal representatives of ESA, ERNO, and MATRA looking on, MDTSCO finally stated that if it had to pay for the development, then NASA would own the design. This terminated the discussion, for such a proposal was unthinkable to European contractors. After everybody else left, the MDTSCO, MATRA, and CIMSA negotiators sat down again and quickly agreed to a contract with a 30 percent reduction in the hours proposed to do the job and a 50 percent cost-sharing approach to the improvements by CIMSA. The ESA representative had told the MDTSCO representatives earlier that a 2–3 percent reduction in cost was the most that could be expected. The next day when the MDTSCO team members arrived in Bremen, the ERNO group, not knowing what had transpired, was waiting to berate them for their difficult negotiating position and for failing to realize that European bids were inviolate and irreducible. When they learned of the agreement that had been reached, they were dumbfounded, to say the least. More importantly, they had a new appreciation for the negotiation ability of this NASA contractor.

ESA's failure to establish a sizable Spacelab utilization effort was one of my major disappointments in the overall program. It was difficult to understand how the Europeans could invest an amount approaching $1 billion in the development of the Spacelab and then propose so few plans for its use. Of course I understand the many factors involved: competition from the German program, the cost escalation of basic Spacelab development, the lack of significant contracts for Europe in the Spacelab operational phase, only one Spacelab procured by NASA, the desire for a better deal for the Europeans in using Spacelab, and the lack of hardware development contracts for European industry. Nevertheless, I believe that an aggressive program of Spacelab use by ESA, both cooperative and cost-reimbursable, would have improved the climate for further cooperative efforts and would have resulted in significant work orders for European contractors in experiment development and integration and for additional items of Spacelab hardware. It also would have stimulated the European scientific community and prepared the way for increased use of the Space Station to follow.

Another European position that I found difficult to understand was their insistence that they should get a better price break in using the Space Transportation System for having developed the Spacelab. We tried to explain to them that we had developed the Space Shuttle, and yet users in the U.S. government paid the same price that was charged to ESA. Somehow, this argument was never accepted by our European friends.

Of all the Europeans I met on this program, none contributed more than Roy Gibson, a very capable and inspiring leader for ESA and a formidable negotiator. A dapper Englishman, Roy had spent much of his life in the Far East, and so, in addition to his fluency in many Western languages, he could switch to some of the tongues of the Orient. He maintained a beautiful home outside Paris, had a reputation as a connoisseur of red wines, and entertained with charm and flair. His manners and speech were inpeccable—in short, he was the consummate diplomat. What impressed me the most, however, was that he treated every one on the NASA team with the same degree of friendship and respect. When the Spacelab program was in serious trouble in 1976, he made the necessary decisions, difficult though they were, to get the program back on track. Since he did not have a technical background, he leaned heavily on his support team when technical judgments were required. Above all, he dealt with each issue in a fair and open-minded fashion. Fortunately, his successor, Erik Quistgaard, was also an experienced administrator and strong supporter of the Spacelab program. He provided consistent leadership during Spacelab's final development phase and into the flight operation period.

The selection of Michel Bignier as Spacelab Programme Director was, in my judgment, a fortuitous choice. After two abrupt changes in ESA leadership during the early years, his selection brought the program much-needed stability. Above all else, Michel was a gentleman, and he was completely honest. Although we occasionally had problems in communicating, I hate to think what the situation would have been had we depended on my French instead of on his English. He opened his office, his records, his home, and his heart to the NASA advisors assigned to his office and to those of us who met with him on a regular basis. I consider it a rare privilege to have had such an outstanding individual as a collaborator in leading this program and, more importantly, as a friend.

9 Integration and Acceptance 1978-1982

AT THE ERNO INTEGRATION HALL

Following the management shakeup at ERNO and the decision to switch to operational software in the fall of 1979, the next action by ESA and ERNO was to establish a task force to review the remainder of the integration and test schedule. There appeared to be no major problems but numerous minor ones related to equipment manufacturing errors, malfunctions, and a poor capability in ERNO for solving these problems. Effectively, ERNO had accomplished less than 25 percent of the progress planned for 1979. By November the task force had prepared a new test schedule with average delays of 7 months from the previous plan. When finally approved in January, this schedule projected the delivery of the engineering model in November 1980 and the flight unit in two deliveries: February 1981 and April 1981.

Meanwhile, out on the floor of the clean room, work continued on the engineering model and flight unit hardware that was available (fig. 89). Typical of the problems encountered during this time were the poor solder joints in the electrical harness of the engineering model, discovered when the input/output unit was removed, and the interference between the module floor and the module shell of the flight unit, apparently due to hole location errors. There was also a poor fit of the floor structure with the mechanical ground support equipment.

Both sets of electrical ground support equipment were available, however, and processing of the engineering model and flight unit could now proceed in parallel (figs. 90 and 91). In fact, the first assembly test (T 004) of the racks, floor, and subfloor of the flight unit was completed in January 1980, a full 2 weeks ahead of the new schedule. Unfortunately, new problems had been encountered at Fokker with the structural fixes to the scientific airlock, and it appeared doubtful that it could be delivered with the rest of the flight unit.

It is interesting to examine what was going on behind the scenes of the integration activities. Although work in the Integration Hall seemed at last to be progress-

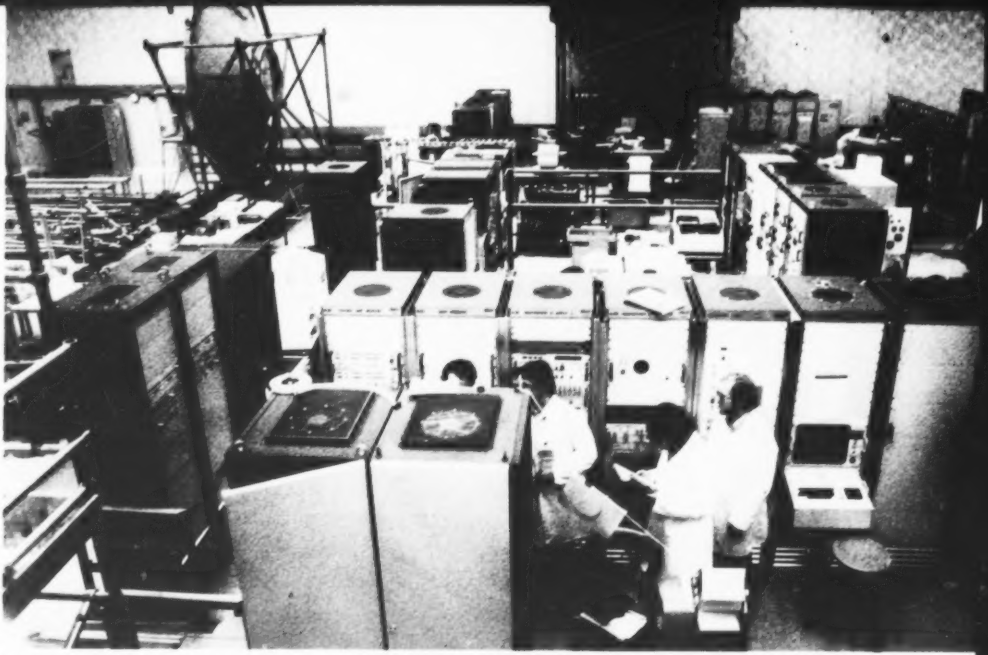


Figure 89. Checkout equipment used for engineering model testing in the ERNO Integration Hall, July 1979. Electrical system integration equipment and unit testers are shown in the background.

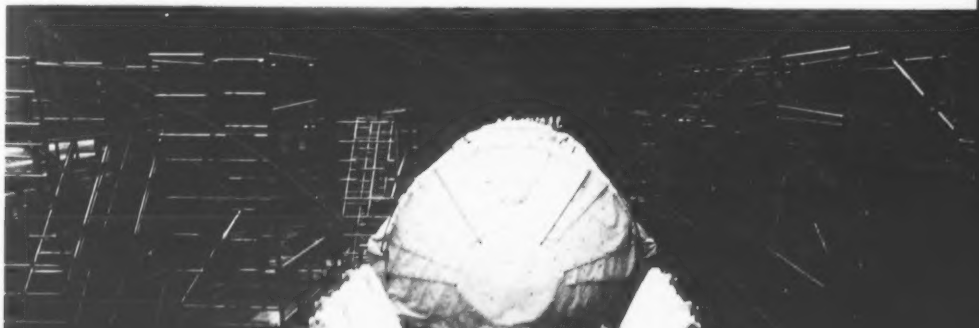


Figure 90. Spacelab engineering model module with insulation blankets and three pallet segments in the ERNO Integration Hall, July 1979.

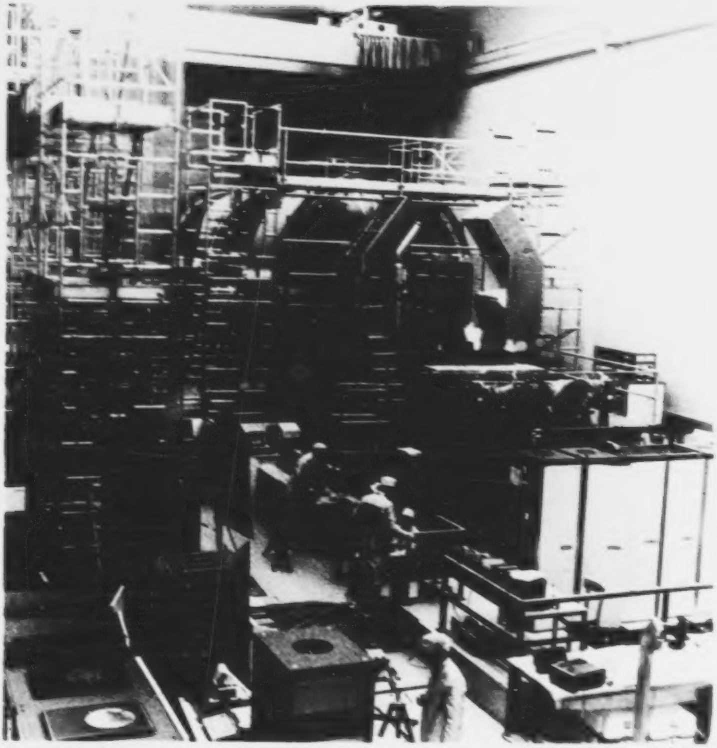


Figure 91. **Spacelab flight unit undergoing test T 004.** The subsystem racks and subfloor are external to the module.

ing well, much supporting documentation was not ready, covering such subjects as processes, correction of deviations, test procedures, qualification, and acceptance. Some 5750 nonconformance reports had been written, and at any one time 1000 were outstanding. These reports were being generated and resolved at a rate of about 200 per month. This represented a considerable backlog of work for all the contractors. Meanwhile, although the igloo for the flight unit had been delivered to ERNO following successful leak tests at ESTEC, a redesign of the igloo support structure was under way at SABCA because of the increasing loads from the Shuttle.

In February, work started on the long module integration test of the engineering model. Just about this same time the 5.7/5.8 coupled loads inputs, which had wreaked such havoc on the IPS program, arrived to be factored into the basic Spacelab design. ESA agreed that it would identify what needed to be done to make Spacelab and its subsystems flightworthy and also recognized its responsibility to make the necessary changes. ESA did not consider itself obliged, however, to make changes solely to maintain payload weight-carrying capability. One option proposed by ESA, which NASA refused to accept, was to reduce the payload capability to accommodate the new loads.

The monthly program reports from ESA to NASA during this year give an interesting history of the course of progress on the engineering model and flight unit and are a good example of the frustrations encountered in trying to monitor the integration effort from across the ocean. From November 1979 to May 1980, the completion of test T 011 on the engineering model, first identified as the short module system checkout test and later identified as the long module system checkout test (which, in fact, it was), was projected for June 26, 1980. There was a cryptic note alongside this scheduled date stating "technical problems with electrical ground support equipment, high-rate data assembly, and related software." In the June 1980 report, completion had slipped to July 31, and an additional long module system test was planned to be completed by June 18. In July, both tests were scheduled for a September 10 completion. In August, both tests were scheduled for October 2. The September report listed the two tests as one and again projected October 2 for completion. The October report stated that the test (including electromagnetic compatibility) was completed on October 1, and with that test the engineering model system integration program was completed. Throughout this entire period, the note about the technical problems remained unchanged. Fortunately for NASA, its resident team at ERNO had better visibility than whoever was preparing these schedule charts for ESA. There had, in fact, been many other problems during the course of the year than EGSE and software. Every time assembly, disassembly, or testing took place, new problems were encountered.

In April 1980, Part I of the Engineering Model Acceptance Review was held. Nine teams evaluated a major portion of the deliverable acceptance data package and some 800 discrepancy notices were written. A major effort would be required to update this documentation, which included such important elements as drawings, the configuration item data list, the "as-built" configuration list, and test reports. Fortunately, the qualification status of the hardware appeared to be quite favorable. Two issues of special importance to both sides were the questions of transfer of work from the engineering model to the flight unit, and "traveled" work (i.e., work which would be completed after delivery of hardware to KSC). Both NASA and ESA were reluctant to accept such proposals from ERNO, but in some cases they were forced to accept the recommendations.

Problems with specific components continued to crop up in the integration testing. The water separator (an identical unit to the one used in the Shuttle Orbiter) failed when water entered the motor housing causing short circuits and overheating. This failure, in turn, caused a complete electrical power shutdown of the Spacelab when correct contingency and recovery actions were not taken. Other delays were caused by the time required for temperature stabilization during the environmental control subsystem tests. Meanwhile, planning was started for transportation of the engineering model to KSC using Air Force C5A transport airplanes for the largest pieces of hardware and a Lufthansa freighter version of the Boeing 747 for smaller items.

The second major test (T 006) of the flight unit was completed in July 1980, although special test equipment had to be used to replace a faulty diverter value. The confirguration for T 006 consisted of a core module complete with the forward end cone, the subfloor subsystems, and an operating subsystem rack train (fig. 92). Unfortunately, as so often happens in a program like this, every report of good news seemed to be accompanied by one of bad news. Four of the flight unit racks, scheduled for early delivery to ESA for use in the European payload preparations for Spacelab 1, were rejected because the associated documentation was not acceptable. Eventually, these problems were overcome. The racks were accepted by NASA and delivered to the SPICE facility in Porz-Wahn in mid-December 1980.

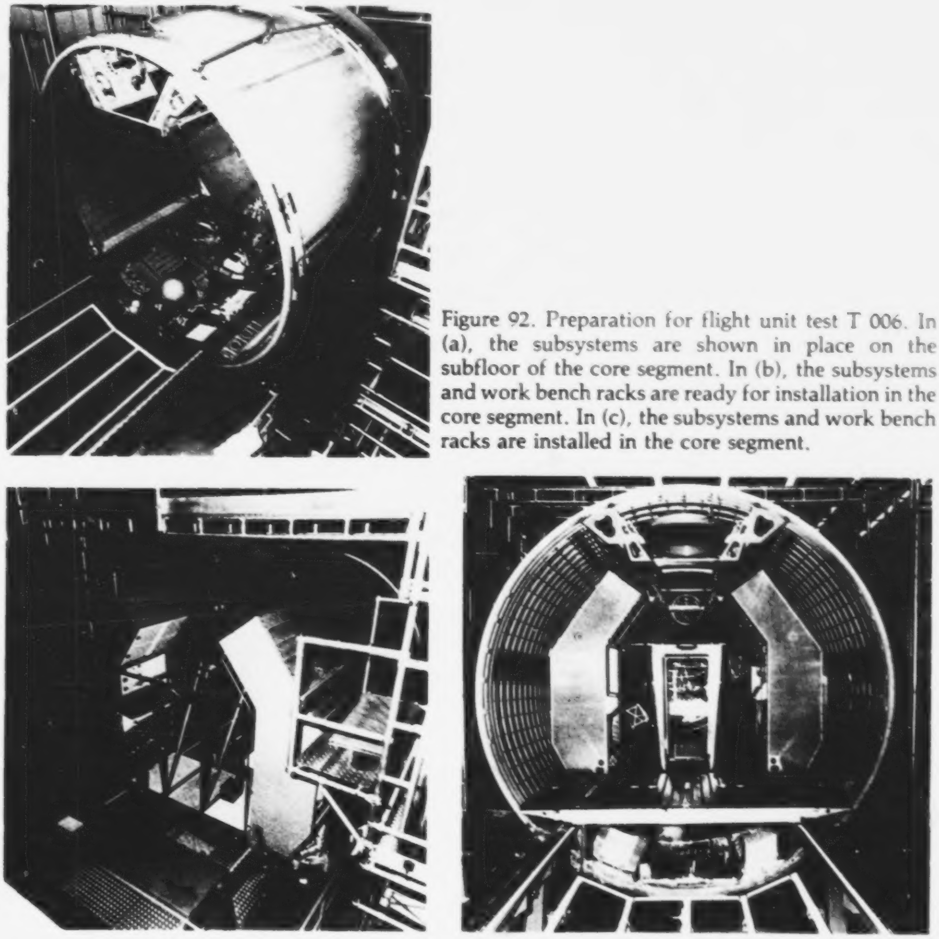


Figure 92. Preparation for flight unit test T 006. In (a), the subsystems are shown in place on the subfloor of the core segment. In (b), the subsystems and work bench racks are ready for installation in the core segment. In (c), the subsystems and work bench racks are installed in the core segment.

With the final push to get the engineering model ready for shipment to KSC, manpower and facility priorities were focused in that direction for the second half of 1980, and progress on the flight unit slowed. As the engineering model was being disassembled for shipment, a new problem was discovered: corrosion around the cold plates. Fortunately this did not turn out to be serious, and corrective action was taken on both the engineering model and flight unit. The Engineering Model Test Review Board on October 20 gave final approval for full disassembly of the engineering model and for start of the formal acceptance review on November 4. This important review, also known as the Engineering Model Acceptance Review Part II, was successfully completed on November 24-25, with the final board giving permission to ship the hardware to KSC.

The final segment of the engineering model was rolled out of the ERNO Integration Hall on November 28, 1980 (fig. 93). This was the occasion for an impressive ceremony, with representatives from the sponsoring European countries, the industrial development consortium, ESA, and NASA watching as the experiment segment of the module began its trip to Hanover, where it would join the other parts of the engineering model awaiting shipment to the U.S. Johann Scheffler of the VFW Board of Directors opened the ceremony with welcoming remarks. He was followed by Quistgaard, the ESA Director General, by Bignier, the ESA Spacelab Programme Director, and by me, the NASA Spacelab Program Director. Finally, Hans Hoffmann, the ERNO Technical Director, thanked the development team for its hard work and congratulated it for achieving this significant milestone. This was a banner day in the history of the program.

The engineering model was subsequently air-transported to KSC in three major shipments. The first C5A containing the core segment, one pallet, and miscellaneous EGSE and MGSE, total weight 33 tons, which arrived at KSC on December 5. A Lufthansa 747 containing two pallets, miscellaneous EGSE and MGSE, and documentation, total weight 40 tons, arrived at KSC on December 8. A second C5A containing the experiment segment, two pallets, and miscellaneous EGSE and MGSE, total weight 37 tons, arrived at KSC on December 13. Unloading of one of the C5A aircraft at the KSC shuttle landing strip is shown in figure 94. All activities related to shipment proceeded smoothly and no major problems were encountered; in fact, only one packing case was slightly damaged. By Christmas, NASA had completed its unpacking and receiving inspection activities. Meanwhile, back at ERNO, the contractor team took a well-deserved vacation. They reported only 10 days of work for December.

Now it was time to take stock of the flight unit situation. It was predicted that Flight Unit 1 (containing the module) would be ready for shipment in June 1981, and Flight Unit 2 (containing the igloo) would be shipped in March 1982. The schedule for Flight Unit 2 was dominated by the need to return the igloo to SABCA for modification to withstand the new increases in Shuttle loads. Although this was a known change due to higher loads, analyses were also continuing at British Aerospace on possible impact to the pallets, at Aeritalia concerning the module and racks, and at Fokker concerning the airlock. Results of these analyses indicated that structural modifications would be required to the pallet hardpoints, the airlock, the

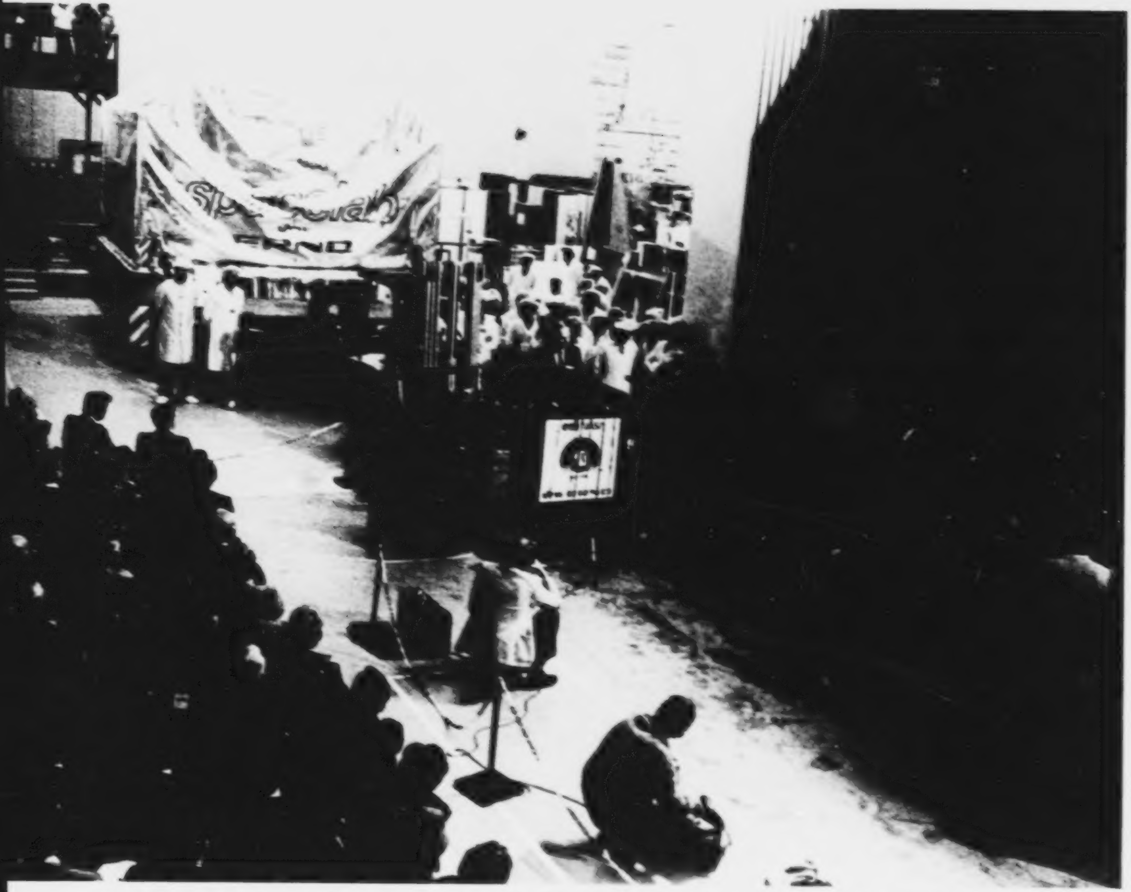


Figure 93. ERNO Technical Director Hans Hoffmann addresses the audience at the engineering model acceptance ceremony in Bremen, West Germany, November 28, 1980. The final element of the engineering model waits in the background for its symbolic rollout.

module floor support structure, the rack attachments, and the end cone spider in order to meet the revised loads. Most important, they would require that the module be disassembled and subsequently reassembled and tested, a procedure that was sure to cause months of delay and consequent cost increases (as much as $20 million). By April it was apparent that delivery of Flight Unit 1 must again be slipped to November.

In order to facilitate structural changes within the module, Aeritalia technicians were detailed to ERNO, and replacement of rivets and other required modifications

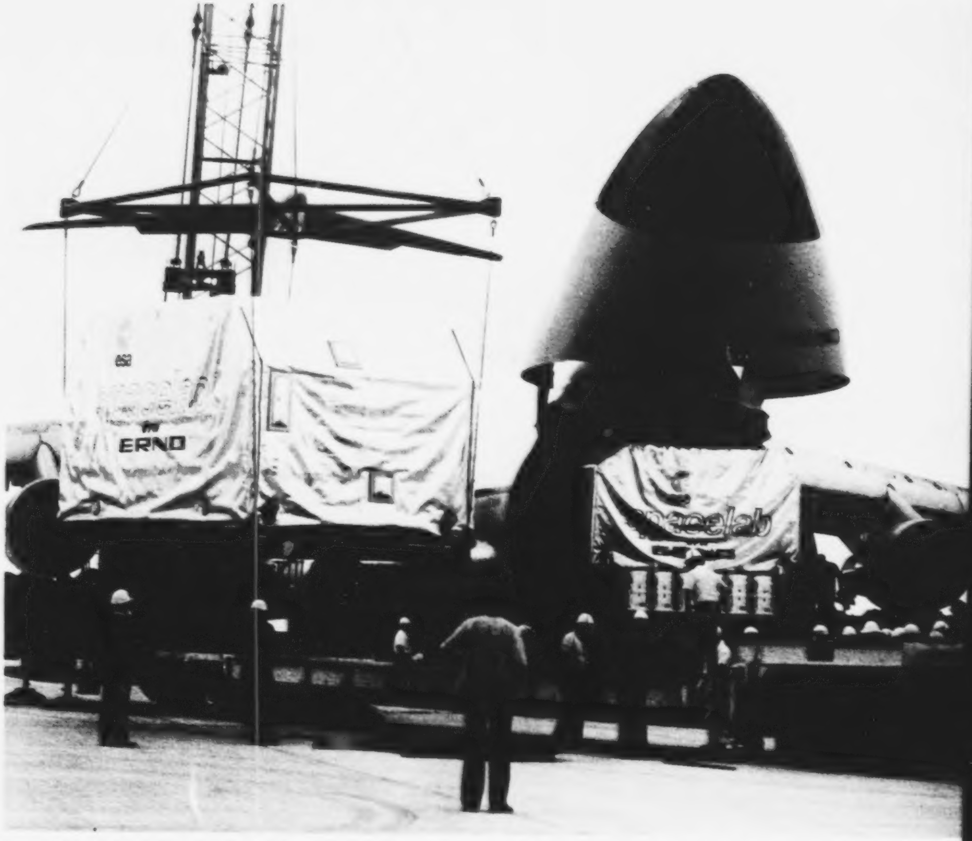
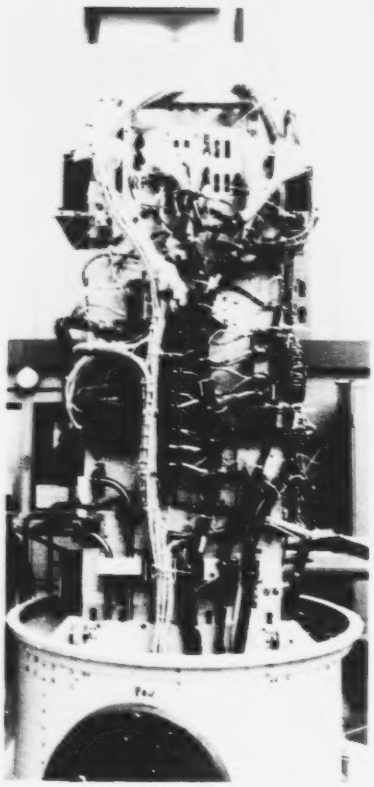


Figure 94. Components of the Spacelab engineering model arrive at the Kennedy Space Center by USAF C5A airplane.

were incorporated on site. Meanwhile, the first part of the Flight Unit 1 Acceptance Review covering EGSE, servicers, flight software, and spares was successfully completed in June. Although some elements of the EGSE had been shipped with the engineering model the previous December, the principal hardware constituting the first set of EGSE had been held over for checkout of Flight Unit 1 and was accepted at this time. It was subsequently shipped to KSC, where it arrived on July 27, 1981. The second set would be retained at ERNO for checkout of Flight Unit 2.

The modified igloo was returned to ERNO for SABCA by June 15, and, after some small modifications were made to the igloo support structure, work began on integrating Flight Unit 2 (fig. 95). A new problem for the schedulers was the continuing slip in delivery of the high-data-rate recorder from Odetics in California, which, during this time period, seemed to be slipping almost month for month. A failure during the qualification tests was cause for concern on this important component of the data system, although it was felt that delivery of the flight unit could proceed without it. The airlock also presented problems when the qualification and flight



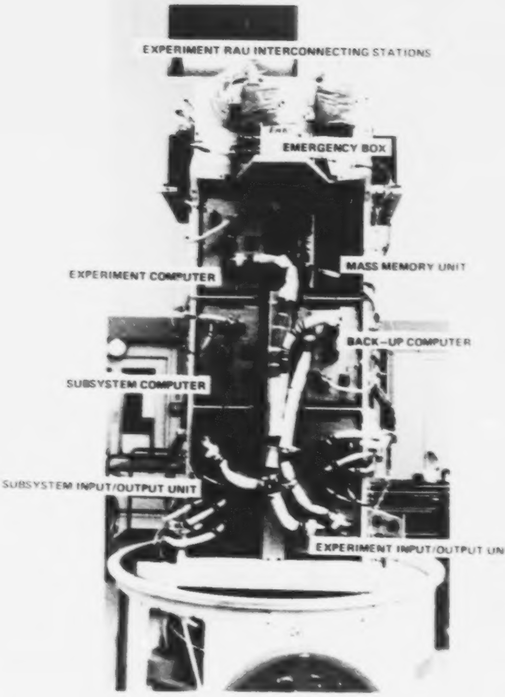

EXPERIMENT RAU INTERCONNECTING STATIONS
EMERGENCY BOX
EXPERIMENT COMPUTER
MASS MEMORY UNIT
BACK-UP COMPUTER
SUBSYSTEM COMPUTER
SUBSYSTEM INPUT/OUTPUT UNIT
EXPERIMENT INPUT/OUTPUT UNIT

Figure 95. Two views of the subsystems mounted in the Flight Unit 2 igloo ready for final integration and testing.

model outer hatches had to be scrapped because of delaminations of the honeycomb.

Despite these problems, the August 31 report from ESA Project Manager Pfeiffer stated that there were no outstanding technical problems. Some items (e.g., the input/output unit and data display units) were being repaired, but substitute units were available for Flight Unit 1 testing. Inevitably, there were still many items of documentation such as parts lists, requests for waivers and deviations, and test reports yet to be completed; however, the Flight Unit 1 subassemblies were reinstalled in the core shell, the experiment train was reassembled, and the harness was reconnected (fig. 96). A test readiness review was scheduled for September 24.

While subsequent Project Manager reports make no mention of this testing, it certainly was successful, because the second part of the Flight Unit 1 Acceptance Review was initated in October and completed November 30, 1981, with a decision by the board to approve Flight Unit 1 for shipment to KSC (fig. 97). A formal Certificate of Acceptance was signed at this time by the Program Directors, Project

Managers, and Acceptance Manager for the two agencies and for the prime contractor. Signing for ESA were Bignier, Pfeiffer, and Lars Tedemann; for NASA were Harrington, Thomas, and Ray Tanner; and for ERNO were Hoffmann, Kutzer, and Hans Stephan. The missing input/output and data display units and the recorder would be delivered to KSC separately. Again, the shipment of hardware would require three separate flights, although the tonnage was somewhat less because this was only a partial unit. The experiment racks with some unit testers and other MGSE were transported in a Boeing 707 on November 13, 1981. The second contingent, including the core and experiment segments and two pallets, was shipped by U.S. Air Force C5A in early December. Later in December the final shipment was by a Lufthansa Boeing 747 to deliver the remaining MGSE, servicers, airlock, and miscellaneous items. Even this reduced complement of materials totaled over 100 tons.

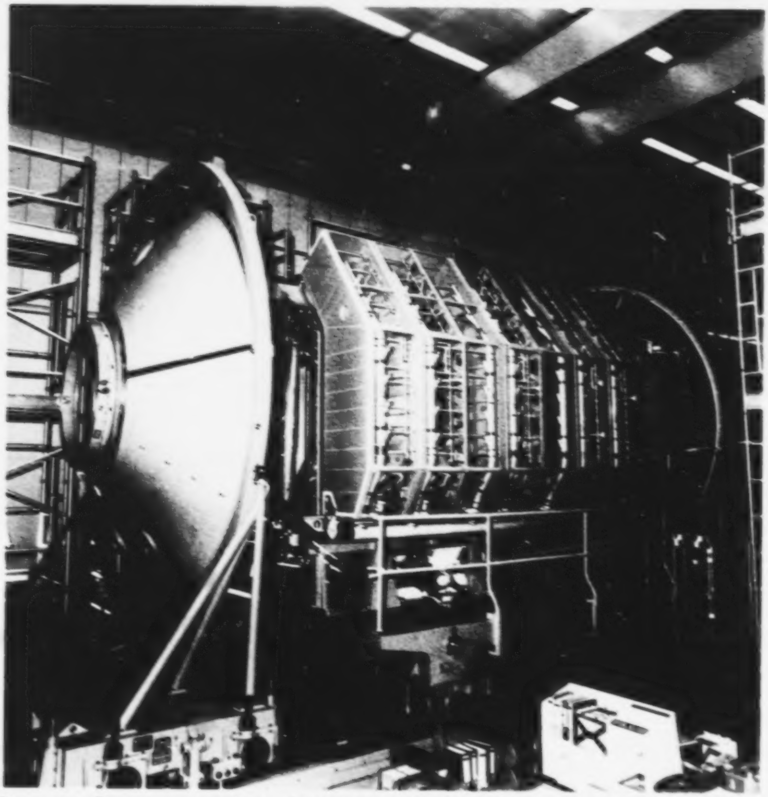


Figure 96. Experiment racks and aft end core ready for final assembly of the Flight Unit 1 module in the ERNO Integration Hall.

Once again, ERNO hosted a ceremony in the Integration Hall on December 4, 1981 to celebrate the acceptance of the first flight unit. Professor Reimer Luest, Chairman of the Board of Directors of the Spacelab Consortium and also Chairman of the ERNO Board (and later to become the third ESA Director General), welcomed the attendees. ESA Director General Quistgaard and Dr. Hans Mark, NASA Deputy Administrator, by their presence and statements, gave strong indication of the importance both agencies placed on the achievement of this important milestone. Mark's speech, delivered in German, was particularly well-received. Jim Harrington, NASA Spacelab Program Director, expressed his excitement to the attending press representatives on receiving the first flight unit and NASA's readiness to prepare it and the payload for the first mission, now scheduled for September 1983. His ESA counterpart, Michel Bignier, emphasized the success of the program to date, but cautioned that the first operation on board the Shuttle would determine its

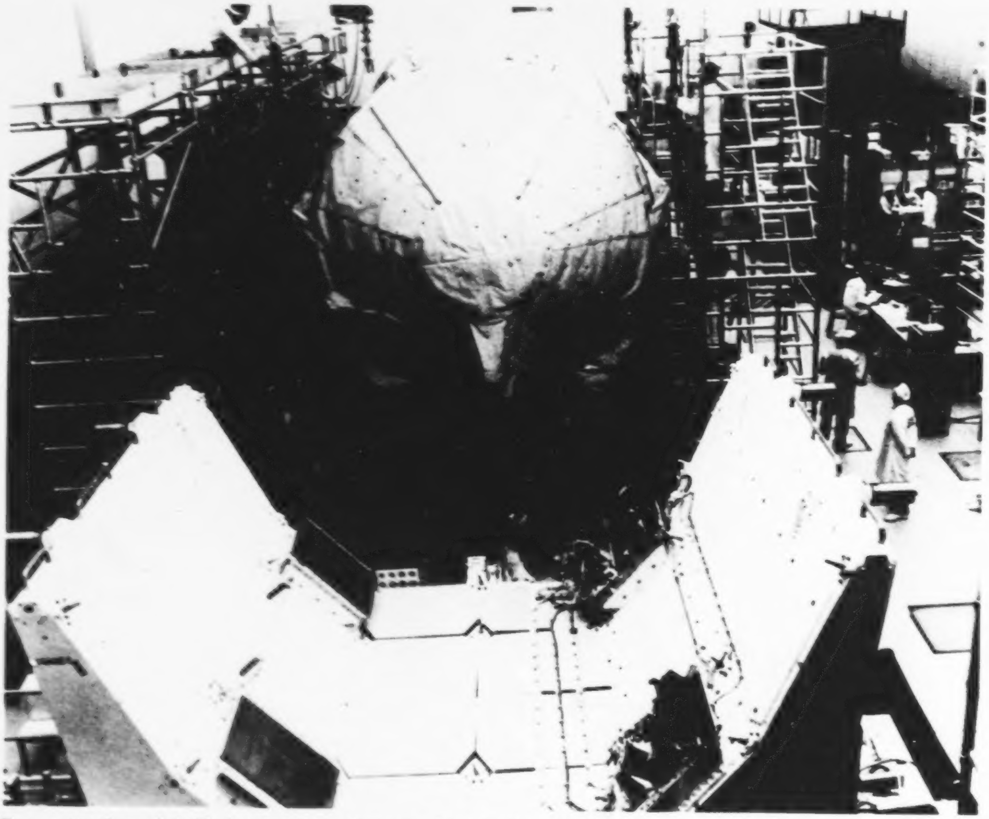


Figure 97. Spacelab Flight Unit 1 undergoing final testing at ERNO.

real success or failure. They were joined by Hans Hoffmann, ERNO Managing Director, who remarked how proud ERNO was of this accomplishment and how he hoped Spacelab would be a tool to be used by Europe, America, and other countries in the decade ahead.

On December 11, after a 10½-hour nonstop flight, the C5A cargo aircraft landed with its load of module segments and pallets on the Shuttle landing strip at KSC. The ERNO transport team and ERNO Managing Director Hans Hoffmann were welcomed by Dick Smith, KSC Director, John Neilon, Manager of the Cargo Projects Office, and George Page, Shuttle Launch Director. Now preparations at KSC for the first Spacelab mission could begin in earnest.

With delivery of Flight Unit 1 to NASA, the ERNO integration team turned back to the igloo/pallet tests (figs. 98 and 99). On December 7, 1981, some 3 weeks late, testing resumed on the Flight Unit 2 systems. During the next few months, testing progressed fairly smoothly with problems on such items as the multiplexer, the input/output coupler, and the harness for the electrical power distribution box. Mechanical problems appeared with one gask-o-seal and some brazing had to be reworked. Troublesome though these problems may have been, they only caused minor perturbations to the scheduled delivery in mid-year. Eventually the Failure Review Board was satisfied and approved disassembly for shipment. The final Flight Unit Acceptance Review began on June 1 and was completed with the board meeting on July 3 and signing of the second Certificate of Acceptance on July 8. Except for the substitution of Al Ryan for NASA Program Director Harrington, and Jochen Becker in place of Hans Stephan as ERNO Acceptance Manager, the signators were the same as for Flight Unit 1.

This time only two flights were required to transport the hardware and accompanying documentation. A Lufthansa Boeing 747 delivered the second set of EGSE and miscellaneous items, and then on July 29 the final shipment of large components, this time containing the igloo and final three pallets, was accomplished when the C5A took off from Hanover for KSC. The Memorandum of Understanding had committed ESA to delivery of the flight unit about 1 year before the first planned Spacelab mission. Since the Spacelab 1 flight was now scheduled for September 30, 1983, that commitment had been achieved with time to spare. Even more important, most of the hardware necessary for the first mission had already been received at KSC the previous December, some 21 months before the planned flight date. This was indeed a formidable achievement by the European team.

It is important to recognize the many contributions and sacrifices of NASA team members who served in liaison posts in Europe during the integration and acceptance period. During 1980 there was a significant "changing of the guard" as Gerald Bishop, Raymond Lawrence, Thomas Marshall, Robert Spencer, and William Wilkinson finished their tours of duty in the resident office at ERNO and returned to key program assignments at MSFC. In the same period, Eldon Raley and Emmett Crooks returned to new assignments at KSC, Bill Oyler having preceded them in August 1979. The places of these important and experienced engineers were taken by Leo Hall (the new resident team leader), Billy Adair, Sherwood Anderson, and Robbie Brown (from ESTEC) of MSFC; and Glen Snyder, Elgin Kirkland, and

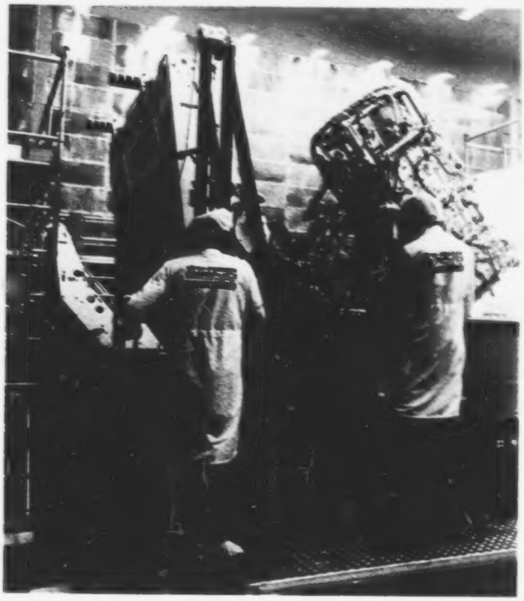
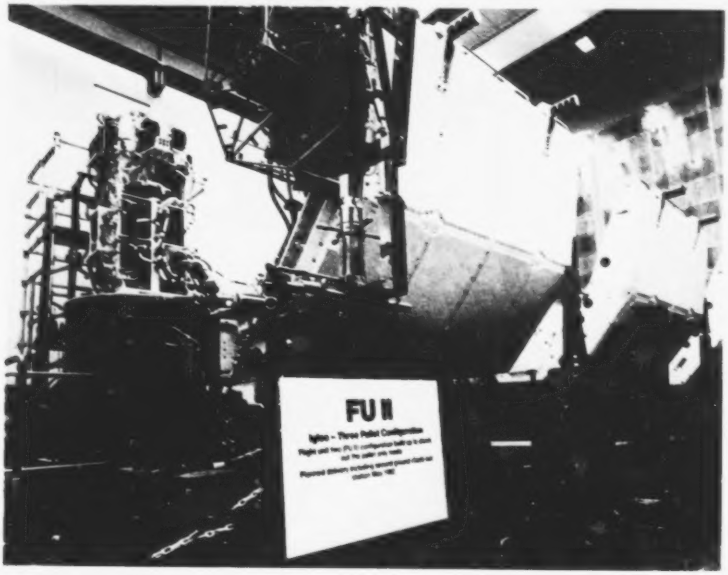


Figure 98. Spacelab igloo being installed on the end frame of the pallet for integrated testing.

Figure 99. The final checkout configuration of Flight Unit 2—an igloo with three pallets—is shown at ERNO.



Ed Wright of KSC. In 1981, Snyder, Kirkland, Wright, and Wally Jordan returned to the U.S. and Jack Hamon and Tommy Knight from KSC joined the resident office at ERNO for the final years of activity.

In the meantime, back at ESTEC, Andy Kromis was encountering serious health problems, and in 1981 he had to give up his liaison post, to be replaced by Chris Hauff from MSFC, who had already spent 2 years at ESTEC in a software assignment earlier in the program. In 1982, Hauff closed down the NASA Spacelab Liaison Office at ESTEC and moved to ERNO to head the liaison team during the final follow-on production activities. Donald R. Andrews from MSFC was the last engineer to transfer to Europe for Spacelab support at ERNO in June 1982. From 1982 to 1984 the resident office was gradually phased down until Hauff had the dubious distinction of planning the closing of his second NASA overseas office. (Actually, Tom Knight of KSC was the last NASA resident team member to leave in 1985.) It was the end of an era.

IN THE UNITED STATES

While all the integration and checkout activities on the mainline Spacelab hardware were being successfully completed in Europe, various activities were also under way in the United States.

ORBITAL FLIGHT TEST PALLETS

Mention was made earlier of NASA's plans to fly engineering model pallets on some of the orbital flight tests (fig. 100). NASA had initially requested four pallets which could be flightworthy for OFT missions. However, Bignier wrote to me on May 2, 1977 and advised that only three engineering model pallets would be flightworthy, the others having been utilized in the test program in such a manner that they could not be flown. At the May 3-4, 1977 meeting of the Joint Spacelab Working Group, Jim Harrington presented a NASA proposal for six preliminary options to meet the NASA requirement. It was later agreed that one flight unit pallet would be delivered early to provide the fourth flightworthy pallet, if needed. When the orbital flight test program was reduced from six flights to four, it was decided that only two Spacelab pallets would be flown: the first would carry a set of Earth resources experiments on the second Shuttle flight, and the second would carry a set of scientific instruments on the third flight. The first payload would be developed by Johnson Space Center under the sponsorship of the NASA Office of Space and Terrestrial Applications and would be called OSTA-1, and the second payload would be developed by Goddard Space Flight Center under the sponsorship of the Office of Space Sciences and would be called OSS-1. From the Spacelab standpoint, an interesting difference in philosophy was adopted by the two groups: the first payload

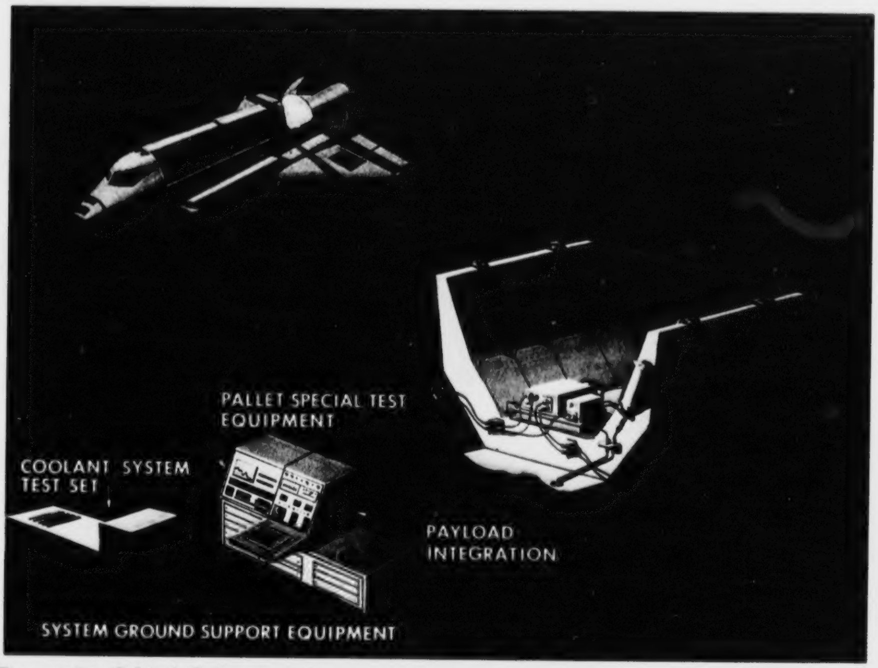

PALLET SPECIAL TEST EQUIPMENT
COOLANT SYSTEM TEST SET
PAYLOAD INTEGRATION
SYSTEM GROUND SUPPORT EQUIPMENT

Figure 100. Orbital flight test pallet concept.

would be integrated and checked out at KSC; the second payload would be integrated and given a preliminary checkout at Goddard.

In July–August 1978, a Critical Design Review for the OFT pallet system was conducted. Then in October the newly developed flexible multiplexer/demultiplexer (from the Orbiter program) was accepted from Sperry and the first OFT pallet structure was accepted at British Aerospace. The pallet structure, shown in figure 101, was next sent to ERNO for final preparation for shipment to the U.S. It was placed on a barge, which, in turn, was put on the merchant ship *Bilderdyk* for its journey to Savannah, Georgia. From Savannah to Cape Canaveral, the pallet was floated on its barge along the intercoastal waterway, arriving at KSC on December 4, 1978. The second pallet followed the same path to arrive at KSC on April 30, 1979. One of the lessons learned from these shipments was that the ocean can provide a very rough ride for space-qualified hardware. Subsequent shipments would rely instead on air transportation.

During the receiving inspection of the first two pallets, paint was found to be peeling from some surface areas. This would provide the first test of the carefully coordinated plan for post-delivery change control. Who would decide the course of action to take? How could the problem be corrected on hardware still in Europe?

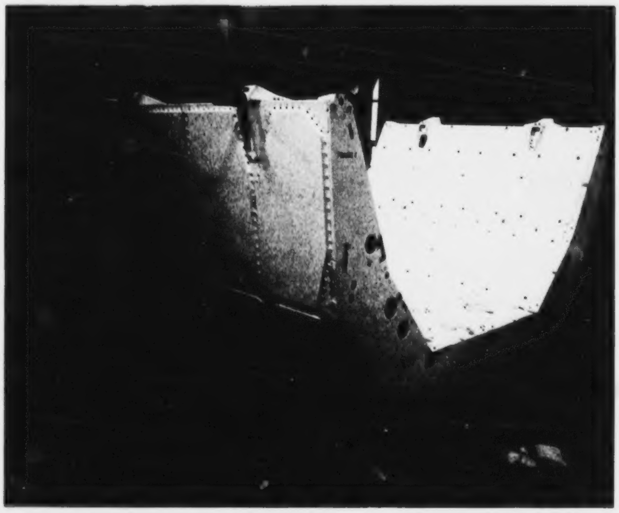


Figure 101. The engineering model pallet being readied for shipment to ERNO from the British Aerospace facility in Stevenage, England, in 1978.

Who would pay for changes to these pallets and to those at British Aerospace or ERNO? Would there be an international incident over this first problem with European hardware to be flown on the Shuttle? Fortunately, the answer to the last question was a resounding no. The entire team of NASA and MDTSCO on the one side and ESA, ERNO, and British Aerospace on the other joined hands to determine the cause of the flaking paint, to develop a repair procedure for those pallets already affected, and to avoid the problem on future pallets.

Investigation showed the cause to be improper surface preparation and poor painting procedures. The panels had been hand abraded rather than vapor blasted, and the anodized surfaces had been rinsed in hot water, rather than cold, causing a surface glaze. There had been excessive delays in painting after anodizing and between paint coats, resulting in probable contamination. It was decided to locally strip the areas of poor adhesion, then clean and repaint them. The viability of this approach was demonstrated by employing it on a number of sample specimens which were exposed to thermal vacuum testing and then subjected to tape peel and standard bend tests to ensure proper adhesion. Fortunately, the Apollo Telescope Mount clean room, which had been left intact at the end of the high-bay area of the O&C Building, provided an ideal environment for completion of these repairs with minimum delay.

A second problem was cause for even greater concern. NASA had been aware for some time that materials used in the engineering model pallets were susceptible to stress corrosion. It was felt that this was acceptable because the OFT pallets would be lightly loaded and only used a few times, at most. When the pallet hardpoints were bolted to the longeron cap and booms, however, the gaps exceeded specification when the proper torque was applied to the bolts. Rather then overtorquing the bolts, which could have worsened the stress corrosion danger, shims were installed to eliminate the gaps.

One final concern was raised about the engineering model pallet load-carrying capability for the OFT flights. Both British Aerospace and ESA were anxious to limit the use of the engineering model pallets on Shuttle flights in the hopes of developing a need for NASA to procure additional flight unit pallets. Also, being ultraconservative about the flight use of these structures, whose design had been frozen very early and which were originally planned to be used in ground-handling exercises only, ESA and British Aerospace set an arbitrary load limit of 1617 kg on each pallet, about half the design load of a normal flight pallet. When the OSS-1 payload weight reached 2315 kg, there was some alarm that this OFT mission was in jeopardy. Fortunately, analyses showed that the load was acceptable, and processing continued.

At the KSC Operations and Checkout Building, the NASA and MDTSCO team was delighted to finally have some hardware to prepare for flight, after years of facility modifications and paper studies of flow plans, schedules, analyses, and procedures. The electrical harness and avionics subsystems were mounted on the pallets, together with the active thermal control system consisting of the freon pump, cold plates, and associated tubing. After resolution of the paint peeling and hardpoint gap problems, problems were discovered with some of the NASA hardware. The secondary structure for mounting a cold plate and several avionics boxes had defective welds. Substitute platforms were machined and retrofitted during the staging process. By November 1979, both pallets were ready for the next step: Level IV integration of the payload. The first pallet was turned over to the Office of Space and Terrestrial Applications for experiment installation in the O&C Building. The second pallet was turned over to the Office of Space Sciences for transport to Goddard and installation of its experiments.

ORBITER/SPACELAB INTERFACE TESTS

Early in the program ESA had required NASA to provide it with a set of Shuttle interface verification equipment. The exact makeup of this equipment was never defined, but it was expected to be a mechanical and electrical equivalent of the Shuttle, insofar as the Spacelab would interface with it. It was obvious that this simulator could become very expensive to NASA and cumbersome to transport to Europe. Questions were raised whether it was really necessary and how it could be assured that such equipment would be identical to a flight Orbiter. NASA argued that since the simulator would have to be built to a set of interface specifications, why not build the Spacelab to those same requirements?

Eventually it was agreed that the Shuttle/Spacelab Interface Control Documents would be the principal means of assuring that the Spacelab would fit in the cargo bay and operate with the Orbiter. The requirement for Shuttle interface verification equipment was dropped. In order to hedge our bets, however, several interface devices and tests would be preserved. The electrical ground support equipment would include an Orbiter interface adapter to provide an electronic simulation of the Orbiter/Spacelab interface. The cargo integration test equipment (CITE) stand at KSC would provide an Orbiter simulation for checkout of the fully assembled Spacelab before it was actually inserted in the real orbiter cargo bay for its first mission. In addition, some avionics components of the Spacelab would be sent to the Shuttle Avionics Integration Laboratory (SAIL) at JSC for specific interface checks. By April 1979, two sets of tests had been completed in the JSC laboratory using European-supplied development components from the Spacelab data system. Among the objectives were to evaluate the interface performance of the Spacelab with the Orbiter's master timing unit, the pulse code modulation master unit, the multiplexer/demultiplexer serial data transfer links in various operating modes and to compare performance characteristics of the Orbiter and Spacelab data bus cables. In general, the problems encountered during these tests proved to be minor.

Nevertheless, until the day that the Spacelab 1 configuration successfully completed its tests in the CITE stand, some 4 years later, both JSC and KSC personnel had strong reservations about this approach, which had been forced on them by Headquarters and MSFC program offices. They felt that this complicated Orbiter/Spacelab avionics interface should have been fully tested in the JSC SAIL facility.

STANDARD MIXED CARGO HARNESS

One problem facing the Shuttle planners at JSC was how to accommodate the variety of payloads planned with minimum delay to Shuttle turnaround time. It soon became evident that, if every payload developed its own electrical harness, the Orbiter would be required to replace miles of cabling between missions. JSC and Rockwell conducted a study and proposed the development of a standard mixed cargo harness (SMCH), which would provide electrical and signal interfaces to several places within the cargo bay rather than at a single point at the forward bulkhead. The major advantages of this approach was a reduction of turnaround time when converting from Spacelab to another cargo (or vice versa) of 18 to 22.5 hours. Of course, there were disadvantages such as increased weight, but the advantages seemed to outweigh the disadvantages. The JSC/Rockwell proposal was presented to the Spacelab Program Office in April 1979, and the following June, Chet Lee (then Director of Space Transportation System Operations) and I instructed Glynn Lunney, the JSC Manager of the Shuttle Payload Integration and Development Program Office, to plan on the use of this standard harness in lieu of unique wiring for Spacelab. The cost to the Spacelab program was not to exceed the $4.6 million budgeted for two sets of Spacelab utility kits. Other programs would provide the remaining funding. The weight impact to Spacelab missions would be an increase of 97 pounds. This has proven to be a wise decision in the program.

LIFE SCIENCE REQUIREMENTS

Some of the most difficult operational challenges for Spacelab planners were presented by the life science users. Their requirements included life support to and data from living specimens during launch and landing and the ability to put the specimens in the Spacelab as late as 12 hours before launch and to remove them immediately after landing. The provision of life support and data turned out to be the simplest of the requirements. The Spacelab design was modified to permit the necessary subsystems to be operated at a reduced power level when on the pad and during launch and landing. This provided the air revitalization, air circulation, and data system to meet life science needs.

The requirement for late access was a different matter. In the 1975 package agreement between Deloffre and me, ESA had agreed to provide for vertical access including whatever special ground support equipment would be needed. Thus, when the Spacelab and Shuttle were on the launch pad, crews would be able to gain access to the Spacelab module or pallets for late placement of life science payloads or, if necessary, changeout of malfunctioning components. During the next several years, many design and operational approaches were considered to provide this access. Initial access to the Shuttle would be provided by the payload changeout room, a part of the KSC launch complex which rolls into place enveloping the Orbiter cargo bay with a protective environment and capability for opening the cargo bay doors. The approach taken by the SENER design team to provide access to the Spacelab was to mount a cantilevered structure from the forward ceiling hatch of the module. Once inside the module, additional platforms and ladders would have to be installed to gain access throughout its 20-foot length.

At the other end of the mission, post-landing, early access posed new problems. Access to the module while the Orbiter is on the landing strip requires the ground (or flight) crew to transit through the Shuttle's airlock, the tunnel adapter, the Spacelab hatch, and transfer tunnel. Protective pads were planned to be placed in the tunnel and hatch areas, and ladders would be necessary at the joggle section of the tunnel and from the module end cone entrance to the module floor. Some kind of dolly was also proposed to transport heavy equipment through the tunnel. At best, KSC estimated that it would take 2 to 3 hours after landing before access could be gained because of the safing operations necessary for the Shuttle and the installation of Spacelab ground support equipment.

At the January 16-17, 1979 Joint Spacelab Working Group meeting, Jack Dickinson, the KSC Spacelab Manager, reported the results of the latest studies to provide improved access to the Spacelab. The achievement of the goal of 12 hours before liftoff appeared to be hopeless with the proposed approach because it would require a minimum of 20 hours after removal of the Spacelab vertical access kit to close the cargo bay doors, remove the payload changeout room, and complete the remainder of the Shuttle countdown. (The most logical solution appeared to be to mount the life science payloads in the Orbiter mid-deck for ascent and reentry if the necessary power and cooling resources could be made available.) At this meeting, Frank Longhurst, the operations manager for ESA, expressed concern over relative deflections between the Orbiter and the rotating service structure which supports the payload changeout room. Such deflections would cause interference between the proposed access kit structure and the platform of the payload changeout room. He also expressed the opinion that ESA should not have to provide a capability for removal of the igloo cover when the Spacelab was in the vertical position, since this was a contingency operation. At our meeting in June, Bignier and I agreed that the ground support equipment for removal of the igloo cover when Spacelab was in the vertical position would not be provided by ESA. Later, when Spacelab 2 was finally ready for launch, this decision would be second-guessed as it would have been desirable to replace a failed computer.

In the meantime, the life science users, represented by Dr. Rufus Hessberg of the NASA Office of Life Sciences, reiterated their requirement for access to living specimens 12 hours prior to launch, preferably at T−8 hours or less. NASA continued its studies of alternative approaches, including access to the module on the pad through the transfer tunnel using some kind of bosun's chair arrangement. On September 12, 1979, Bignier wrote to me expressing serious concern over the escalation of cost of the vertical access kit, then under design review at SENER. The current cost-to-completion for the kit exceeded the amount he had included in the 140 percent program cost-to-completion estimate by a factor of two. Although Bignier's specific request was to change from mounting the vertical access kit on the module hatch flange to mounting it directly to the KSC support structure, his letter was also a call for relief from this difficult financial dilemma. Recognizing that NASA would probably end up using the tunnel access approach to satisfy our life science needs, I asked the Marshall team to evaluate using the same route for contingency replacement of faulty Spacelab components on the pad and relieving ESA of the requirement to provide the vertical access kit. I recognized this as an opportunity to trade ESA's development responsibility for the vertical access kit for an equivalent commitment in some other area.

By the October 2-3 Joint Spacelab Working Group meeting, I was able to offer that NASA would be responsible for providing the vertical access kit, if a suitable trade could be established. Pfeiffer suggested that ESA would provide NASA with an equivalent value of unit testers, equipment which he knew we were very anxious to obtain to support troubleshooting failed components during KSC operations. It was then agreed that the detailed design drawings of the vertical access kit by SENER and unit testers valued at $450 000 would be made available to NASA by ESA, and NASA would develop the vertical access kit.

SPACELAB PROGRAMME BOARD VISIT

During my visit to ESA with Yardley and Frutkin to address the Spacelab Programme Board regarding the proposed barter agreement on September 14, 1978, Yardley invited the board members to visit NASA. The purpose of their visit would be to familiarize them with the Space Shuttle program and to develop their awareness of the total U.S. investment in the Space Transportation System. Discussions during the next year reinforced the feeling that such a visit would be desirable, and a trip was planned for October 16–18, 1979. At the time of the visit, the Spacelab Programme Board was chaired by J. L. Flinterman of the Netherlands and included as representatives A. Hicks (U.K.), R. R. Rissone (U.K.), R. van Welt (the Netherlands), E. Mondre (Austria), J. Laurent (Belgium), M. Jacob (Belgium), L. Porpora (Italy), C. Risch (Switzerland), L. Pueyo (Spain), J. J. Cahen (France), and H. Schreiber (West Germany).

On October 16 the group was welcomed to NASA Headquarters by Deputy Administrator Alan Lovelace, given an overview of the Space Transportation System by Yardley, and briefed on the Shuttle by Dr. Myron Malkin and on STS operations by Chet Lee. Luther Powell, formerly Deputy Manager of the Spacelab Program Office at MSFC, presented a summary of plans for the power module program, which he now headed and which was to be the first step in an incremental approach to a Space Station. After this, Jack Lee and I summarized NASA activities in support of Spacelab. Emphasis was placed on the Spacelab development tasks which NASA had accepted since the start of the program and on the fact that NASA had already spent $64.4 million for Spacelab development, systems integration, and procurement. Dr. Timothy Mutch, Associate Administrator for Space Sciences, introduced NASA's plans for Spacelab utilization, which were amplified by Jesse Moore (who had replaced Bob Kennedy as head of the Spacelab Payload Office) and O. C. Jean of MSFC. Their presentation showed an aggressive program for using the Spacelab three to six times per year after 1982.

On October 17, the board visited Johnson Space Center, where it was welcomed by Center Director Chris Kraft and given a presentation by Bob Thompson, Manager of the Space Transportation System Office. The remainder of the day was spent in briefings on JSC programs in agriculture remote sensing and life sciences and in tours of the Spacelab and Orbiter simulators, the Orbiter mockup and payload integration area, and the Mission Control Center.

The final day, October 18, was spent at KSC, hosted by Center Director Dick Smith and Deputy Gerry Griffin. Dr. Robert Gray briefed the group on Shuttle activities at KSC and John Neilon described STS payload activities. The group then toured the O&C Building to view the Spacelab/payloads processing area, the Orbiter Processing Facility, the Shuttle Processing and Launch Control Center, and Launch Complex 39A.

Whether or not the visit accomplished its objectives for both sides is pure conjecture at this point. Chairman Flinterman sent a very cordial letter of thanks to Dr.

Lovelace on November 8, noting that the board now had a "much better understanding of NASA's formidable undertaking in developing the STS, and NASA's means, in human capabilities and facilities, to meet the challenge and difficulties of operating it." He also expressed the board's concern, as shared with NASA, over the costs of Spacelab utilization and the belief that efforts must be made to decrease these costs. On the whole, it would seem to have been a very worthwhile visit.

SPACELAB 2 CONFIGURATION CHANGES

Early guidelines for the second Spacelab mission had specified that it would employ a pallet-only configuration, so as to verify the operation of the igloo/pallet mode of operation. It was proposed initially that two pallet trains, each consisting of two pallets, would be used (the 2+2 approach). This had been a fairly arbitrary decision, however, and changes in the pallet configuration were considered likely. In late 1977, the Spacelab payload planners, reacting to experiment proposals for the second mission, recommended a change in the Spacelab 2 configuration. It was their desire to fly a large cosmic ray experiment (looking much like a very large egg), which could best be served by employing its own independent structural mount to the Orbiter. This would provide an instrument to explore cosmic ray composition at energies more than 10 times those previously reached and would eliminate most of the weight requirement for one pallet. It was proposed that a three-pallet train be flown in conjunction with the cosmic ray special structure in place of the 2+2 configuration.

I requested Bignier to consider this change, and he immediately responded that it would eliminate the need for ESA to provide a utility support structure (the bridge that supports wire harnesses and plumbing across the gap between the two pallet trains). He pointed out that the impact on the IPS, scheduled to fly on that same configuration, would have to be assessed. He also asked for details about the special support structure for the cosmic ray experiment, concerned that NASA again might be developing a competitive structure for the ESA pallet. Information on the planned mounting structure was subsequently submitted to ESA in May 1978, and Bignier accepted the proposed change during the June 12–13 Joint Spacelab Working Group meeting. He again expressed his concern that this structure would be the first step toward elimination of the ESA pallets entirely. In this regard, Bignier would appear to have been overreacting, because the proposed structure was defintely a point design uniquely suited to maximizing the size of the cosmic ray experiment.

For almost 2 years this was the accepted configuration for the Spacelab 2 mission. Then in February 1980, Jesse Moore came to me with a proposal to modify the configuration again. His proposal was to change from a three-pallet train with igloo to a single pallet with igloo plus a two-pallet train (the cosmic ray experiment mounting structure would remain unchanged). The proposed change was brought on by a recent evaluation of the projected payload instrument and mission-peculiar weights and the load-carrying capability of the three-pallet train. In fact, the payload mass exceeded the 5000 kg limit for the three-pallet train. The payload mass of 6130 kg (including provision for anticipated growth) would be within the limit of 7880 kg for the one pallet plus two-pallet train, even with a weight penalty of 517 kg for extra fittings, wiring, and plumbing.

ESA conducted its own evaluation of NASA's proposal and recommended instead that a two-pallet train with igloo plus a single pallet be used because it would provide a greater mass margin and required no change in Spacelab baseline utilities and because the NASA-proposed configuration was not one of the eight agreed configurations of the ESA development program. NASA Program Manager Jack Lee responded that NASA had considered both configurations and had chosen Moore's because it could use the experiment support platforms already designed, the utilities presented no major problems, and the single pallet with igloo was baselined in Spacelab documentation and did not show evidence of being a structural problem. This, then, was accepted as the new configuration for Spacelab 2 unless later loads analyses showed a need for further changes. As it turned out, this was the last major change in the configuration for the Spacelab 2 mission, with the exception of the IPS, which we now know was to be completely redesigned.

ENGINEERING MODEL

Once the engineering model had been delivered to KSC in December 1980, the NASA and MDTSCO team could begin familiarization exercises with the hardware. Until the first set of electrical ground support equipment was received in July 1981, however, activities were limited to receiving, inspection, and mechanical handling and assembly operations. Several items, notably the mass memory unit and the input/output unit, required retrofit, and the airlock and high-data-rate recorder were being used for the flight unit checkout at ERNO. By May, however, the long module had been fully assembled at KSC. With the arrival of the first set of electrical ground support equipment, emphasis was placed on installation of this equipment in the control rooms overlooking the high-bay area, and the engineering model was readied to serve as a guinea pig for checkout of the total system in its new environment. Finally, in February 1982, the engineering model was powered up to begin tests simulating those to be conducted later with the first flight unit. These tests proved to be extremely valuable for the KSC processing team. Then, in July 1982, when the second set of electrical ground support equipment arrived, the engineering model would be switched to this set for debugging, as the first set began support of the first flight unit in preparation for the Spacelab 1 mission. As shown in figures 102-104, the engineering model proved to be an important pathfinder in this program in training an almost completely new crew at KSC, in verifying handling operations in the new workstands of the O&C Building, in using items of ground support equipment developed in the U.S., and then in working out the bugs as the two sets of electrical ground support equipment were reactivated in the new facility.

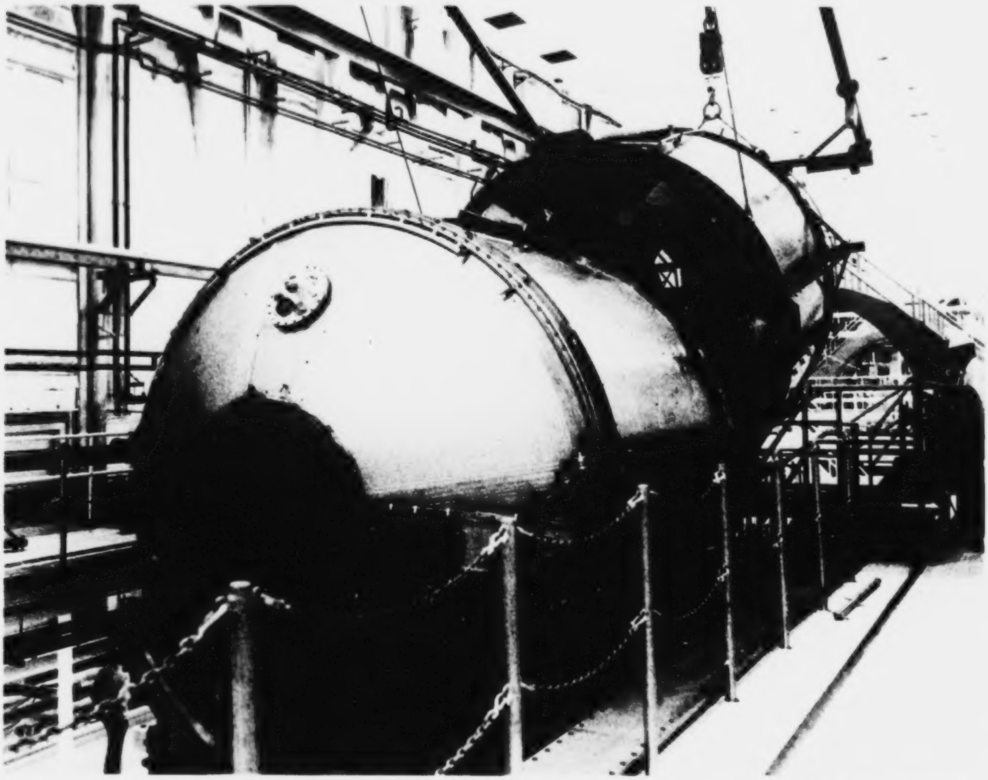


Figure 102. Experiment segment of the Spacelab module being lowered into place next to the core segment in the test stand at the Kennedy Space Center Operations and Checkout Building.

There is little question that these tests contributed immeasurably to the relatively trouble-free processing of the first flight unit.

FLIGHT UNIT ARRIVAL CEREMONY

Following the receipt of the first flight unit at KSC in December 1981, plans were finalized for a suitable Spacelab arrival ceremony to celebrate this important achievement (fig. 105). The highlight of the ceremony on February 5, 1982 was the presence of Vice President George Bush lending top administration endorsement to the occasion. More than 300 invited guests from Europe and the U.S. gathered in the high-bay area of the Operations and Checkout Building where they could see in the background both the engineering model and flight unit hardware on the Spacelab workstands. The ceremony was short but meaningful, with welcoming words from KSC Director Dick Smith, followed by remarks from Dr. Johannes Ortner, now

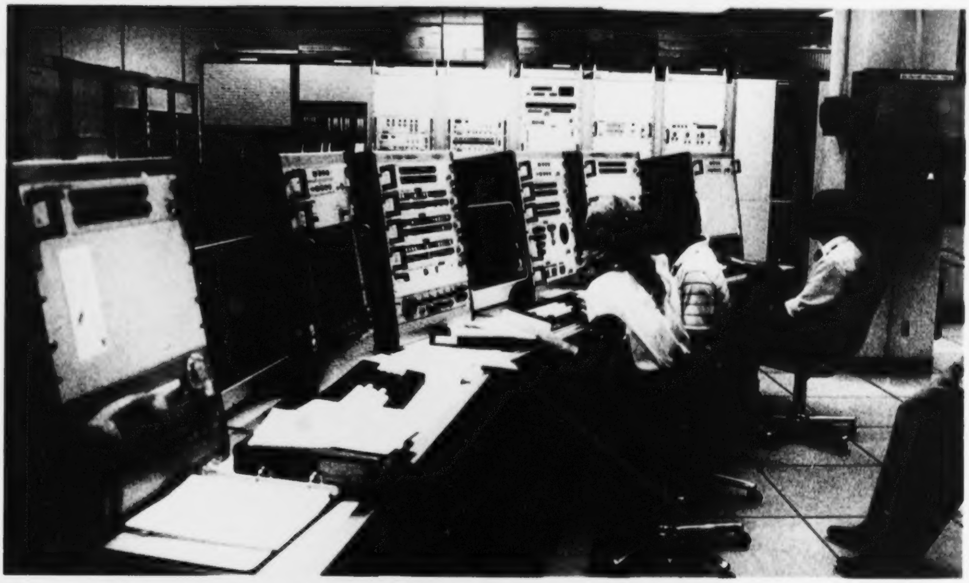


Figure 103. Kennedy Space Center personnel working at Spacelab control room consoles in the Operations and Checkout Building.

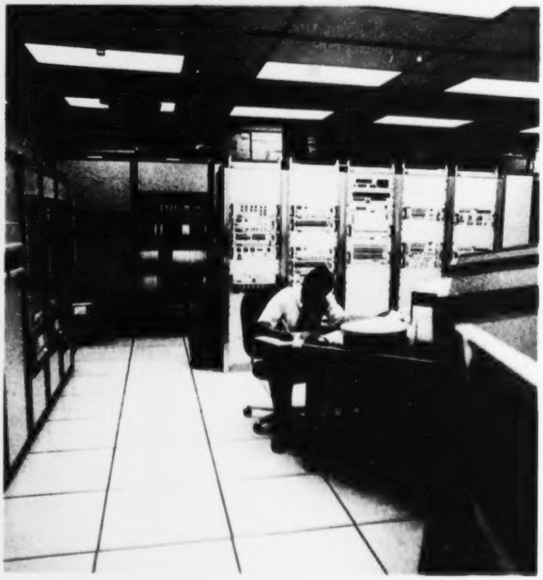


Figure 104. Electrical ground support equipment in the Spacelab control room at Kennedy Space Center.

Chairman of the ESA Spacelab Programme Board, from ESA Director General Erik Quistgaard, and from NASA Administrator James Beggs. In his keynote address, Vice President Bush called Spacelab "the fruit of a lot of hard work," emphasized that the European contribution of Spacelab would permit man to return to space with all the tools for peace, and commented, "If today can be considered Spacelab's birthday, then there are a great many proud parents celebrating." Indeed there were.

Following the ceremony, attendees were given tours of the workstand area and had a chance to see the Spacelab hardware up close and to meet the Mission Specialists and Payload Specialists candidates for the Spacelab 1 mission. A reception, held in the KSC Visitors' Center, was like a family reunion, with participants from the early days of the program rubbing elbows with the new guard who would bring the program to fruition.

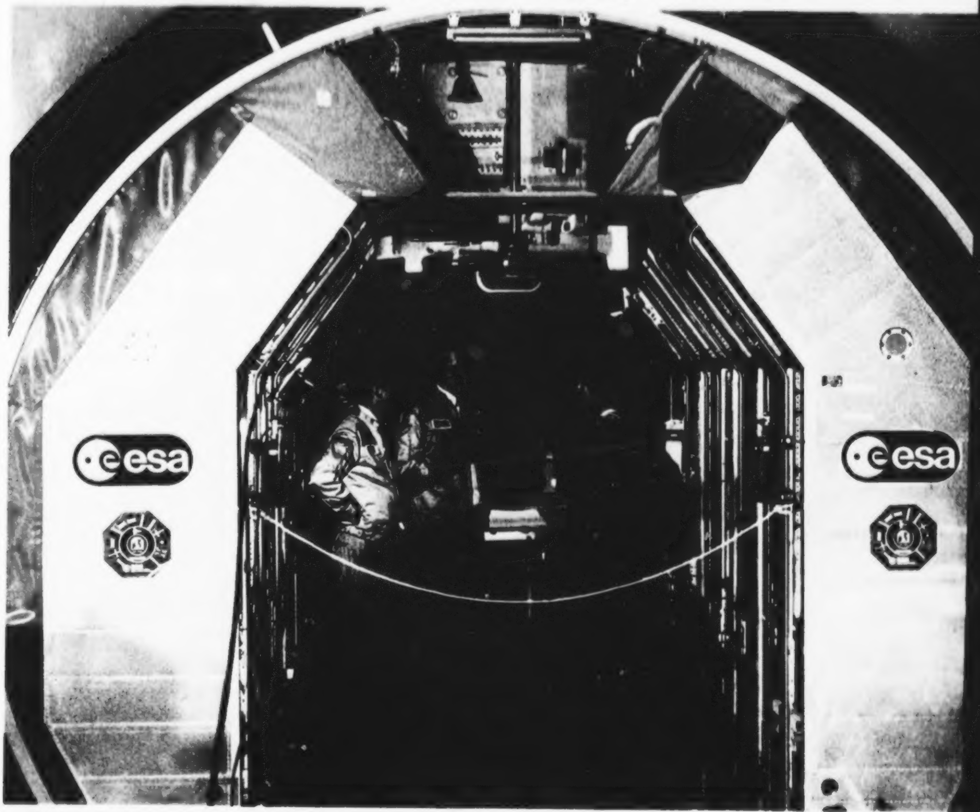


Figure 105. Vice President George Bush (center) inspects the Spacelab module with NASA Mission Specialist Owen Garriott (left) and ESA Payload Specialist Ulf Merbold at the Spacelab arrival ceremony at Kennedy Space Center on February 5, 1982.

Personal Reflections

Memories of my many visits to ERNO would be incomplete if I did not mention a special friendship with Achim Nordmann of the ERNO Public Relations Department. On my first visit to ERNO, this enthusiastic spokesman greeted one of my cohorts, mistaking him for me, and launched into a rapid-fire welcoming speech in his inimitable manner. When he finally paused for a breath, he was told that he had the wrong man, and I was pointed out. Herr Nordmann quickly spun around toward me and launched again into the identical speech, including the history of Bremen, of ERNO, of Germany, the plans for our stay, the schedule of activities, how much they admired NASA and the U.S., how glad they were to have us there, and so on. It was as if he were programmed with an internal recording and one just had to push the button and it would start up again. At each major review at ERNO, Nordmann was always the first one to greet us and the last one to see us off, using a bullhorn to keep the groups in line and meetings on schedule. In later years he seemed to have lost favor in the company, but I always made it a point to stop in to visit Achim and to hear about his latest project to publicize Spacelab. He was very imaginative, encouraging school art contests, radio and TV shows, special issue stamps, and even Spacelab publicity on the boxes of German Kellogg's Frosties cereal. West Germany was well-informed on Spacelab, and Achim Nordmann deserves much of the credit.

Clean rooms in the space industry are always interesting, and the large clean room of the ERNO Integration Hall was no exception. When entering, it was necessary to receive authorization, pass a guard station, and use a shoe scrubber, then to don gowns, hats, and booties before entering the clean room through an air lock which assured a positive pressure of air in the test area so that contamination particles would be forced out. One complete end wall consisted of filters to trap major dirt particles as the atmosphere was exhausted from the room. Despite these precautions, it was interesting to observe that the hats covered only some of the head hair and beards and mustasches were completely uncovered, leaving an obvious source of contamination. As with any clean room, the rigor of cleanliness and the security of the room fluctuated from time to time. No doubt it protected the flight hardware to some extent, but I always question the class of cleanliness that is quoted in such facilities.

Progress on integration and checkout at ERNO was difficult for the management groups to assess in our periodic visits. By the end of 1979 the Integration Hall was jammed with equipment, so it was obvious that hardware was arriving from the co-contractors (fig. 106) Progress on some testing could be identified because of the special setups required, such as the Faraday cage (a copper screen room) which surrounded the Spacelab for the electromagnetic compatibility test. All testing required extensive documentation, so one seldom saw much activity or movement other than an occasional shift of equipment by facility crane or MGSE. Usually technicians sat at consoles or stood at unit testers taking endless measurements and exerting various stimuli to the hardware under test. The actual progress could only be measured by the tests completed and the test results, which could best be evaluated for us by the on-site ESA and NASA resident teams. Fortunately these very dedicated and experienced people were able to cut through the confusion of red tape, changing

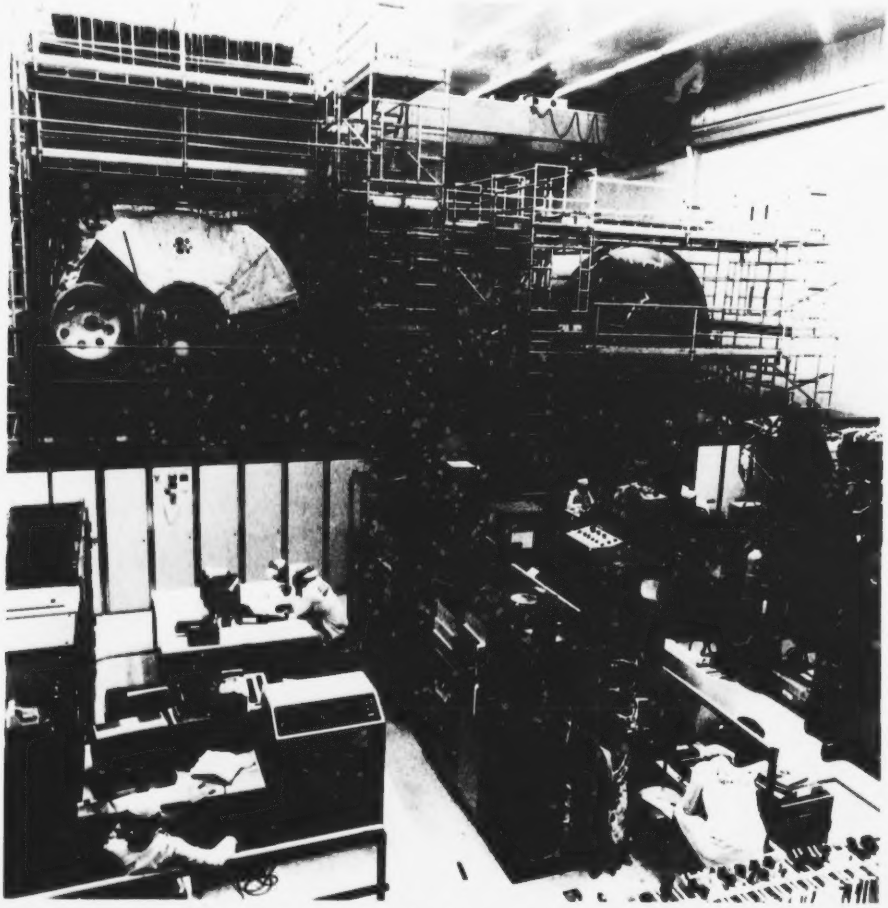


Figure 106. Peak of integration activity in the clean room at the ERNO Integration Hall. The flight unit module is shown partially assembled on the right; the engineering module is on the left.

schedules, and language barriers to keep us informed on the state of the integration and checkout program. A visit to the "bungalow" which housed the resident team was like a visit back home, except for the multilingual secretaries, not often found at KSC or MSFC. They proved essential to the accomplishment of working and living in a foreign land for our team members and, incidentally, were a great help to visitors in conducting work and making the inevitable changes in travel plans.

The weekend of November 26-30, 1980 was undoubtedly the most unusual Thanksgiving holiday of my life. The Europeans, not thinking of our American holiday, had scheduled the Engineering Model Acceptance Ceremony in Bremen on the day after Thanksgiving. It was my 43rd trip to Europe since the start of discussions on the program, and although I had retired from NASA effective November 20, I was working as a rehired annuitant until year's end and was designated the senior NASA representative at the ceremony. My wife, Barbara, had been able to accompany me on very few of my overseas trips, but this was one trip that I insisted she make. We stayed in a small French-style inn on the outskirts of Bremen and the entire trip was like a second honeymoon for us.

I had given much thought to what I would say at the ceremony and enlisted the aid of a good NASA friend, Leo Werner, who had been born in Germany, thinking that I would give my speech in German. After struggling with my pronunciation of the difficult German sentences, Leo suggested that I give the main speech in English and make some closing remarks in German, recognizing that some of the ERNO attendees would appreciate the effort. In my remarks, I commented on the achievements that had been made during the past 10 years and noted that the Shuttle was approaching its first launch and that pallets of the engineering model were already being prepared for early Shuttle flights. I complimented the Spacelab team on its accomplishments and conveyed congratulations from the NASA Administrator. I also reflected on the climax this day presented for Jack Lee and myself, with both of us leaving our Spacelab jobs for new opportunities. Finally I said in German, "I'm sorry that after so many visits to Bremen, I still don't speak any German. But perhaps it is sufficient to say to you: I am a Bremen town musician." This paraphrased the famous speech by President John F. Kennedy in West Berlin when he stated, "Ich bin ein Berliner," only this time I related to the Grimm fairy tale, immortalized in a statue in the Bremen marketplace, of the Bremen town musicians—a rooster on top of a cat, on top of a dog, on top of a donkey. The audience was delighted and responded with much laughter and applause. Later, several people asked me which one of the musicians I was. At a later party for the ERNO workers, I responded that the Spacelab program was somewhat like the Bremen town musicians. NASA was the rooster riding on the cat, ESA. ESA in turn rode on the dog, ERNO, the prime contractor, and ERNO rode on the donkey, which represented the poor co-contractors. Everyone thoroughly enjoyed this analogy and agreed that it was apt—especially the co-contractors who were present.

Two other events concluded the day. A reception was held in the beautiful Bremen city hall, where we were greeted by Senator Karl Willms, to whom I presented a framed picture of the planet Saturn taken on a recent Voyager flyby. Then ERNO provided luncheon for 200 in the underground Ratskellar. The entire day was a memorable occasion, and never did I feel closer to my European friends.

The paint flaking incident from the orbital flight test pallets can be laughed at now, but at the time there was serious concern. It could have been very expensive to NASA and also could have established a bad precedent for solving problems that might be encountered later. Fortunately, this matter was resolved relatively quickly and did not presage similar problems with the remaining hardware to be delivered. On the occasion of my retirement, my friends at KSC presented me with a piece of the flaked paint encased in clear plastic and suitably inscribed as a reminder of my "first Spacelab international incident."

It is interesting to look back on the vertical access kit controversy and to see what finally happened in this regard. NASA did develop a bosun's chair system for providing late access to the module. This approach was used in the Spacelab 3 mission, and animals and other living specimens of the life science payload were installed from 22 to 17 hours before liftoff. The life science users were pleased with this arrangement, even though their early demands had stated 12 to 18 hours before liftoff as a firm requirement. After the Shuttle landed at Edwards, the ground crew was able to install ground support equipment and remove the animals within 3 hours of touchdown. Again, this was considered to be a reasonable time interval before readaptation to 1 g could occur. As with so many other user requirements, early requests were often used to push the Spacelab designers as far as possible, but when it came down to the final strokes, reasonable minds prevailed and acceptable compromises were reached.

The ESA Spacelab Programme Board was often a thorn in the sides of ESA and NASA program managers. As would be expected, its members often reflected their own national desires rather than the best interests of the total program. In the case of the proposed barter agreement and in discussions about Shuttle/Spacelab pricing policy, the board failed to recognize the overwhelming contribution and commitment of NASA in the total Space Transportation System as compared with ESA's Spacelab commitment. The trip to the U.S. in October 1979 seemed to have an important impact on the board members. Certainly the board's willingness to support the program when the cost to ESA approached 140 percent and its continued support of the IPS development despite its many delays and problems demonstrated a desire to see the program through to its conclusion. Nevertheless, individual members, even after the successful Spacelab 1 mission, expressed their dissatisfaction with the fairness of the Spacelab agreement and pledged to be more difficult negotiators on future cooperative proposals.

Another European board worthy of special mention is the Spacelab Board of Directors. This board, made up of senior representatives from the ERNO-led consortium, met regularly to assure that the entire European industrial team was aware of problems within the program and was applying every resource at its disposal to solve the problems. The board members also provided a second avenue to the participating governments in securing increased funding for the program. There is no question but that this board constituted a powerful mechanism in support of the overall program.

After a year of retirement from NASA and my Spacelab responsibilities, it was a wonderful opportunity for me to return to KSC for the Spacelab arrival ceremony. It was hard to believe that so much could have been accomplished in less than a decade, even though early schedules had projected even more ambitious accomplishments. NASA did a wonderful job in trying to recognize all those who had contributed to the program, and it was a great experience to renew friendships made across the years as well as across the ocean.

10

Readiness For Flight 1978 - 1983

FLIGHT HARDWARE AND SUPPORT SYSTEMS

The preceding chapters recount the story of the planning, design, development, and testing of the Spacelab hardware and related support systems. At last, it was time to prepare for the flight phase of the program.

OSTA-1 PAYLOAD

The first pieces of Spacelab hardware to enter the flight phase were those necessary to support the NASA Office of Space and Terrestrial Applications payload, OSTA-1. An Announcement of Opportunity had been issued for experiments that would be compatible with orbital flight test missions. In general, these experiments were to be relatively simple and self-contained. They were to require minimal participation by the crew, since the early flights would have only a two-person crew, most of whose time would be spent flying the Orbiter and conducting flight tests to determine Shuttle performance and the induced Shuttle environment. When it became evident that the second flight of the Shutttle required the Orbiter to spend much of its orbital time in a z-local vertical position with the cargo bay opened toward the Earth, a candidate list of Earth-viewing experiments was selected from the experiment proposals submitted in response to the Announcement of Opportunity.

Dick Moke of the JSC Earth Resources Program Office began working on this payload in 1976 and by late 1977 funding was approved for a payload scheduled to fly in July 1979. After considering other options, it was decided to mount the principal experiments on one of the British Aerospace pallets provided by ESA as a part of the Spacelab engineering model. Working with Bill Johnson of the MSFC Spacelab Program Office, Moke made arrangements for the Marshall team to stage the pallet with the necessary secondary support structures, cold plates, plumbing, electrical harnessing, and control electronics (multiplexer-demultiplexer) to be ready to accept the experiments provided by JSC. Rockwell supplied much of the hardware for this purpose.

When the Earth Resources Program Office at JSC was dissolved, Moke became Deputy in the Payload Integration Office but retained his role as Mission Manager. For a short time he was therefore able to approve for the Integration Office actions he was taking as Mission Manager. Later, at the urging of Jesse Moore at Headquarters, JSC established a separate mission management organization within its science office, to which Moke was transferred as Manager until OSTA-1 was successfully flown in November 1981, some 2 years later than originally scheduled. In addition to Moke, other key individuals in the OSTA-1 payload development were Program Scientist James V. Tarinek, and Program Manager Louis J. Demas at NASA Headquarters and Mission Scientist Andrew E. Potter and Mission Manager Gerald P. Kenney at JSC.

The OSTA-1 payload consisted of five experiments designed to carry out investigations in Earth resources and environmental observations to be mounted on the pallet and two other experiments, one involving advanced technology and the other a life science engineering test, to be located in the Orbiter cabin. The largest instrument to be mounted on the pallet was the Shuttle imaging radar-A, a side-looking synthetic aperture radar to create two-dimensional images of the Earth's surface. It was hoped that these images, studied in conjunction with ground observations and with other radar images made using other parts of the energy spectrum, would provide a geological analysis to help locate mineral resources. The Principal Investigator was Charles Elachi of the Jet Propulsion Laboratory.

The second pallet-mounted instrument was the Shuttle multispectral infrared radiometer, an instrument to evaluate 10 spectral bands in the infrared region to determine their effectiveness in discriminating geological units. The goal was to determine which spectral bands should be included in a future high-resolution imaging system for mapping rocks associated with mineral deposits from space. The Principal Investigator was Alexander F. H. Goetz of the Jet Propulsion Laboratory.

The third pallet instrument was the feature identification and location experiment to measure the spectral reflectance of scenes at red and near-infared wavelengths and determine the ratio of these measurements. The objective was to distinguish at the gathering stage data representing water, vegetation, bare ground, snow, or clouds. The Principal Investigator was Roger T. Schappell of Martin Marietta Aerospace.

The fourth pallet experiment was the measurement of air pollution from satellites, which measured the distribution of carbon monoxide in the middle and upper troposphere. Its purpose was to indicate the validity of using orbiting spacecraft to measure environmental quality. The Principal Investigator was Henry G. Reichle, Jr. from Langley Research Center.

The final instrument mounted on the pallet was the ocean color experiment to seek ocean areas in which a high concentration of chlorophyll-bearing algae shifts the pure blue of ocean water to green. This information would be used to map the distribution of algae and thus help to locate fish schools or ecological disturbances caused by pollutants. The Principal Investigator was Hongsuk H. Kim of Goddard Space Flight Center.

One experiment to be conducted from the Orbiter cabin was the night/day optical survey of lightning, in which the crew would use a motion picture camera to film the lightning flashes of nighttime thunderstorms. Lightning spectrographs would be obtained simultaneously. During the day, lightning discharges would be delineated by a photo-optical system in which audio pulses would be recorded on magnetic tape. Simultaneous motion pictures of the cloud structure would be obtained. The Principal Investigator was Bernard Vonnegut of the State University of New York at Albany.

The other experiment to be conducted in the Orbiter cabin was the heflex bioengineering test, a preliminary test in support of a planned Spacelab 1 experiment. The purpose of the test was to determine the effect of soil moisture content on the growth of plants in zero gravity. The Principal Investigator was Allan H. Brown of the University of Pennsylvania.

Once the experiments had been selected, the next job was for the Principal Investigators and Co-investigators to ready the flight hardware for installation on the pallet and in the crew cabin, and for the JSC team to supervise the installation of this equipment at KSC, using its supporting teams of technicians and engineers from Rockwell, MSFC, and KSC. A key set of hardware for checkout of the experimental equipment on the pallet was the Pallet Integrated Test Set (PITS). Breaking new ground every step along the way, this payload was the first one negotiated under a Payload Integration Plan (PIP) with Glynn Lunney's Payload Integration Office at JSC. This plan, the basic agreement between the Space Transportation System and the payload, served as the road map for payload integration and mission preparation.

As pointed out in chapter 9, the preliminary staging of the first pallet had been completed by November 1979, and the pallet was turned over to the Office of Space and Terrestrial Applications for installation of experiments. By this time, it was already apparent that the OSTA-1 mission would not be possible before March 1981. Nevertheless, it was decided to proceed with experiment installation and checkout, which was accomplished during the next several months, using for the first time the Level IV rails (workstand) (fig. 107). Then commenced a long wait for the first Shuttle flight primarily due to problems with installation of the thermal protection tiles, and the OSTA-1 pallet and its payload were temporarily stored in the Apollo Telescope Mount clean room. In late 1980, however, the pallet was moved to the cargo integration test equipment (CITE) stand (another first) to prepare for a simulated integration with the Orbiter. A symbolic turnover of OSTA-1 from Rockwell to JSC was accomplished on March 4, 1981, and a second turnover to KSC took place on March 10. Following the successful completion of the tests in the CITE stand, a payload Certification Review was completed in July 1981 to certify that OSTA-1 was prepared to support the STS-2 (second Shuttle flight) Flight Readiness Review, certify that the OSTA-1 integrated payload and carrier were ready for testing with the Orbiter, and affirm the operational readiness of the supporting elements of the mission. Although this was an Office of Space and Terrestrial Applications payload, the Spacelab Flight Division was located in the Office of Space Sciences, therefore this review was chaired by Andy Stofan, Acting Associate Adminstrator for Space Sciences. The review covered the readiness of the OSTA-1

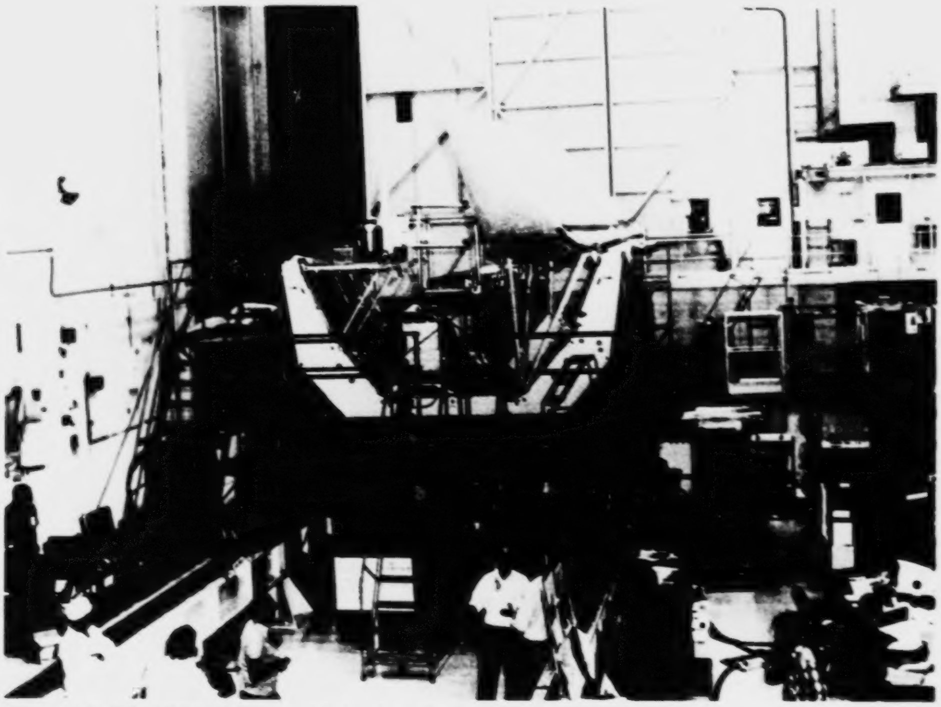


Figure 107. The OSTA-1 payload being installed on the Spacelab pallet in the Operations and Checkout Building at Kennedy Space Center. The Apollo Telescope Mount clean room is shown in the background.

payload, the individual experiments, the pallet and its support systems, the ground operations, and the flight operations.

About the same time as the certification review, the OSTA-1 payload and pallet were loaded into the payload canister for transfer from the O&C Building to the Orbiter Processing Facility. The canister is a large, environmentally controlled container, about the size and shape of the Orbiter cargo bay, designed to protect payloads while in transit from the O&C Building to the Orbiter Processing Facility or from the Vertical Processing Facility directly to the launch pad. OSTA-1 was the first real payload to utilize this canister.

The installation of OSTA-1 into the Orbiter proceeded fairly smoothly (fig. 108), and final checkout and mission simulations were conducted. Orbiter processing proceeded in a normal fashion and the second Shuttle launch occurred on November 4, 1981. Intended to be a 4-day mission, problems occurred almost immedately with the loss of one of the Orbiter's three fuel cells. Because of this, the mission duration was shortened to only 56 hours. With the requirement to check out the Canadian-developed remote manipulator system, which was being carried for the first time, the mission was constrained by a very tight time schedule. Nevertheless, with use of the onboard computers to rearrange the payload management menus and with ground control of some of the experiments during times when the crew was asleep or otherwise engaged, OSTA-1 provided an abundance of data and utilized all its film.

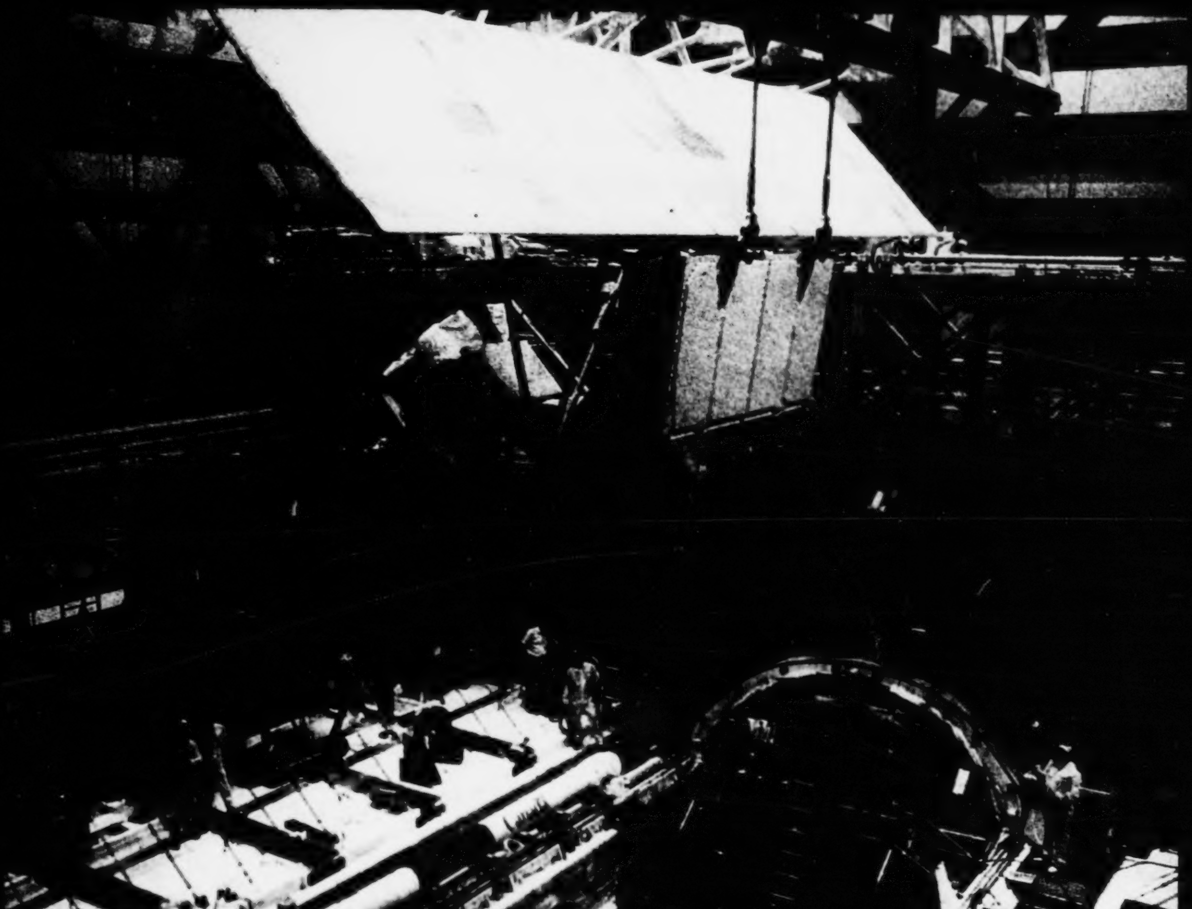


Figure 108. The Spacelab pallet carrying the OSTA-1 payload is shown being lowered into the Orbiter cargo bay.

From the Spacelab viewpoint, OSTA-1 demonstrated the outstanding performance of the pallet for carrying experiments. The large antenna was aligned to within a couple of arc-seconds while the pallet was in the CITE stand. It was rechecked after installation in the Orbiter and after being returned to the ground after the mission, and it was still in alignment. More importantly, the data indicated that it remained perfectly flat during the mission, as there was no radar data distortion. Even the thermal deflection, which had been projected to be up to 2 degrees, was considerably less than 1 degree. Thus the first mission of an important part of the Spacelab had demonstrated that the design and operational procedures were, in fact, good. Spacelab had met its first flight challenge and responded with flying colors.

OSS-1 PAYLOAD

The second flight challenge for Spacelab hardware and procedures was the Office of Space Sciences payload, OSS-1. Like its predecessor, OSS-1 would consist primarily of a set of instruments mounted on one of the British Aerospace pallets delivered by ESA as part of the Spacelab engineering model. This time, however, the experiments would be of a scientific nature, with emphasis on deriving information on the Orbiter environment that would be important for future scientific instruments to be mounted on this new breed of payload carrier. Another difference was that the OSS-1 payload would be mounted on the pallet at Goddard Space Flight Center.

In order to pave the way for scientific payloads which might fly on the Shuttle, Goddard had established a payload planning group under Dave Grimes, who was succeeded by Joe Fuller and later by John Busse. This group proposed to Headquarters a series of candidate payloads for the six planned orbital test flights. When the number of test flights was reduced to four, only one Goddard payload survived, OSS-1, to be launched on the third flight, STS-3. By this time the Office of Space Sciences had named Bob Kennedy as its Program Manager and Eric G. Chipman as its Program Scientist. At Goddard, Ken Kissin became the Mission Manager and Werner Neupert the Mission Scientist. Another key member of the management team at Goddard was Ted Goldsmith, who was in charge of the systems and also served as the Operations Manager.

OSS-1 was characterized by its Goddard creators as a "pathfinder mission" because it would check many factors that could not be pretested on Earth, but that would affect future scientific observations from the Shuttle. Typical of the factors to be examined were the thermal variations, the effects of Orbiter-generated particles and gases, and the degree of electrical charging on the vehicle. Scientific disciplines to be included were astronomy, space plasma physics, and life sciences. During the STS-3 mission a variety of orbital attitudes would be examined: nose toward the Sun, tail toward the Sun, cargo bay toward the Sun, and the "barbecue mode" in which the Orbiter would be rotated to equalize temperatures on all surfaces. Some of the experiments on OSS-1 could be conducted throughout the mission, whereas others, particularly those oriented to solar measurements, would be conducted while the Orbiter was in an orientation to best suit those observations.

Of the nine experiments in the OSS-1 payload, only the plant lignification in weightlessness experiment was located in the crew cabin. Mounted within a locker in the mid-deck compartment, this experiment was to be the first of several scheduled for Orbiter flights in which a variety of seedlings would begin growth in weightlessness. The Principal Investigator was Joe Cowles of the University of Houston.

The other eight experiments were mounted on the Spacelab pallet (fig. 109). The plasma diagnostics package was essentially a self-contained satellite for measuring the magnetic environment around the Orbiter. It would make measurements while fixed to the pallet, then would be picked up by the Orbiter's remote manipulator system (mechanical arm) and moved around in predetermined sweeps to map the Orbiter's fields in and near the cargo bay and out to 15 meters distance. On the later Spacelab 2 mission, this satellite would be released to measure the more

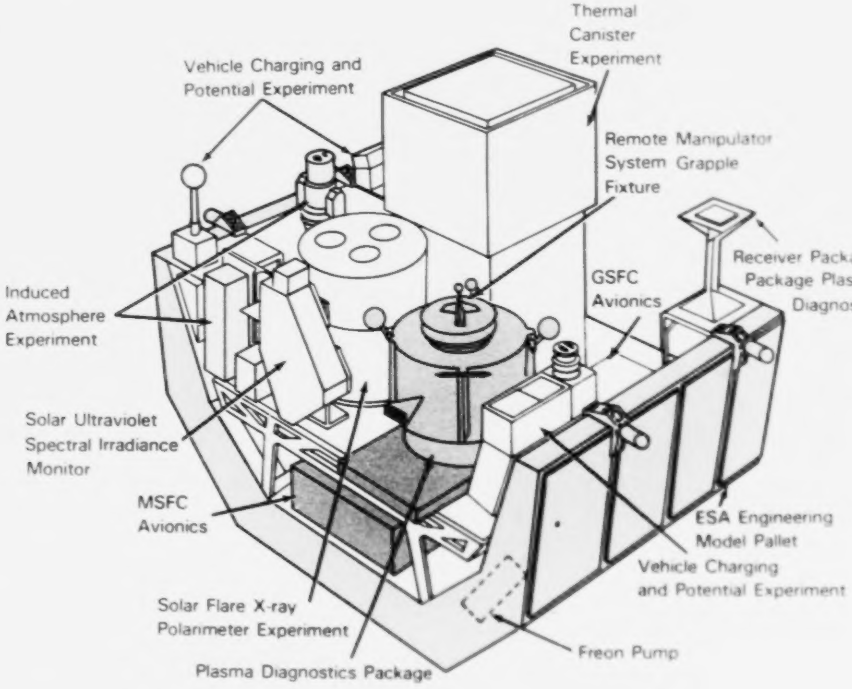

Thermal Canister Experiment
Vehicle Charging and Potential Experiment
Remote Manipulator System Grapple Fixture
Receiver Package Package Plasma Diagnostic
GSFC Avionics
Induced Atmosphere Experiment
Solar Ultraviolet Spectral Irradiance Monitor
MSFC Avionics
ESA Engineering Model Pallet
Vehicle Charging and Potential Experiment
Solar Flare X-ray Polarimeter Experiment
Freon Pump
Plasma Diagnostics Package

Figure 109. The OSS-1 payload and pallet support subsystems.

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distant fields around the Orbiter. The Principal Investigator for the plasma diagnostics package was Stanley Shawhan of the University of Iowa.

The vehicle charging and potential experiment was to study the electrification phenomena of the Orbiter by inducing changes in electrical potential in a controlled manner with a low-power fast-pulse electron gun. It was anticipated that the resulting beam could make the surrounding gases visible. Charge and current probes were also mounted on diagonally opposite corners of the pallet with sensors to record the electrical effects. Peter Banks of Utah State University was the Principal Investigator for this experiment.

The Shuttle-Spacelab induced atmosphere experiment was a photometer-camera system to define the optical properties of the dust and volatile materials emanating from the Orbiter. These measurements were essential to determine the threshold at which meaningful astronomy could be conducted from the Orbiter. The Principal Investigator was J. L. Weinberg of the University of Florida.

The solar ultraviolet spectral irradiance monitor was another experiment planned to be carried later on the Spacelab 2 mission. Its purpose was to improve the accuracy of far-ultraviolet flux measurements of the Sun. Interest in accurate measurements of the Sun's ultraviolet radiation and its range of variability has been heightened by the increasing concerns over long-range changes in the Earth's atmosphere and climate. Ultraviolet radiations, absorbed in the outer reaches of the Earth's atmosphere, play an important role in determining the physical properties of the upper atmosphere and, by implication, in influencing the condition of the lower levels that affect human life and livelihood. Guenter E. Brueckner of the Naval Research Laboratory was the Principal Investigator for this experiment.

The solar flare X-ray polarimeter, as its name implies, was to determine the polarization of X-rays emitted during a solar flare. The intent was to settle a question of conflicting theories about the physical processes that drive solar flares. The OSS-1 payload would include three analyzers for the most thorough sampling of solar flare X-rays ever made. The Principal Investigator was Robert Novick of Columbia University.

The contamination monitor package was another experiment to measure the induced contamination environment within the Orbiter's cargo bay. The package contained four temperature-controlled quartz crystal microbalances to measure the accumulated mass of molecular and gas contaminant on their outside surfaces. The objectives were to monitor the buildup of condensible volatile material during all phases of ascent, on orbit, and during descent; correlate the mass buildup with payload activities, Shuttle operational events, OSS-1 instrument performance degradation, and data from the induced environmental contamination monitor flown as part of the Orbiter development flight instrumentation; and determine the temperature necessary to "boil off" the accreted material. Jack Triolo of Goddard was the Principal Investigator.

The microabrasion foil experiment consisted of aluminum foil sheets bonded to a plastic substrate to obtain information on the particle densities of micrometeorites which impact the exposed material during the mission. Measurements of the numbers, chemistry, and density of these tiny particles can yield basic information about the history of the solar system. The Principal Investigator was J. A. M. McDonnell of the University of Kent at Canterbury.

The final OSS-1 payload experiment was the thermal canister, a simulated container for space experiments in which heat pipes would be used to provide a controlled thermal environment against temperature extremes which in space can vary from +200°C in sunlight to −200°C in the shade. Stanford Ollendorf of Goddard was Principal Investigator for this experiment.

For the central brainpower of the OSS-1 payload, Goddard utilized some spare electronics built for the International Ultraviolet Explorer, a flight-proven automated satellite system. Pulse-code modulated science data were thus provided to the Payload Operations Control Center at JSC using the instrument ground support equipment and the payload ground support equipment developed by Goddard. Although NASA had agreed with ESA that a "hybrid" pallet capability would not be developed (see chapter 7), by any reasonable yardstick this would have to be judged a competitor to the ESA-developed pallet-only system, although the IUE equipment was technically a part of the payload, had minimal capability, and was used only on this one mission.

When the pallet was being staged at KSC with the basic pallet support equipment, Goddard pressed for an early turnover of the pallet for payload integration, even though it was evident the mission would not be flown, at the earliest, until late 1981. Nevertheless, Goddard argued that the investigator support teams would have to be kept at full strength until the payload was integrated and checked out, after which a mothball period prior to lauch would make more sense. The pallet was transported from KSC to GSFC over the road in late 1979, using the Payload Environmental Transportation System, a truck-mounted container with environmental control that had been developed by KSC for just this purpose. Although transportation by road posed certain planning and scheduling problems, in the end it was a relatively straightforward operation. Goddard, in the meantime, had built a complete full-scale wooden mockup to work out interface problems between the various instruments, the secondary support structure, and the electrical harnesses and plumbing lines. In addition, since the experiments were arriving at Goddard before the pallet, there was time to perform an electrical mating of the experiments with the OSS-1 avionics system. All seven experiments with electrical interfaces encountered problems, which required each to be returned to the Principal Investigator at least once for rework.

Once the pallet was at Goddard, the inhouse team began installation of the secondary structures required to locate the various experiments at the proper place for viewing angle and accessibility (fig. 110). Typical problems with the cooling system required tearing down the system to flush out impurities and to replace clogged filters. Then, as the equipment was added to the pallet, a continuing deflection of the U-shaped structure (which, after all, could not be perfectly rigid) required adjustment and realignment of instrument mountings. As with the basic Spacelab and the OSTA-1 payload before it, some structural modifications had to be made to

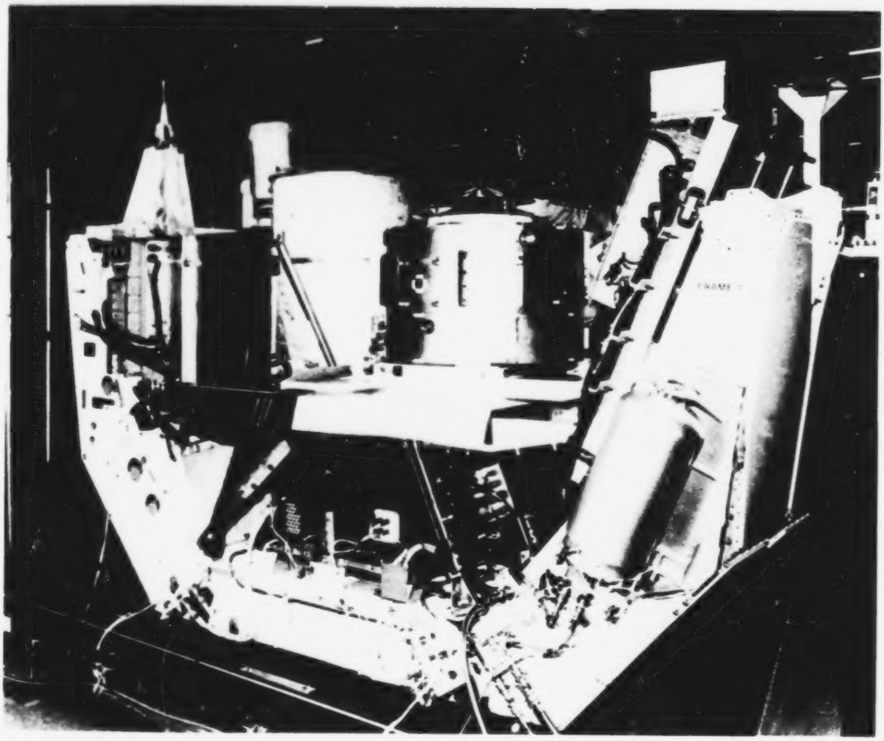


Figure 110. The OSS-1 payload integrated on the Spacelab pallet.

the mounting points to account for increased Shuttle load factors. These and other problems were soon resolved and the payload put through its paces, including a final acoustic test. OSS-1 then was put in mothball status (sometimes referred to as dwell time) until it was time to transport the assembled payload to KSC for final launch preparations.

In late 1981 and early 1982, the final hierarchical reviews and simulations were conducted to assure readiness for launch. On December 8, the OFT Pallet Program Manager's Review was conducted at MSFC. Then on December 15, the OSS-1 Pallet Pre-Integration Review was also conducted at MSFC, followed by the Cargo Readiness Review at KSC on January 5, 1982. An OSS-1 simulation was conducted at JSC on January 26–28. Finally, the Flight Readiness Review was completed on March 9, and STS-3 was launched on its 7-day mission on March 22, 1982 with the OSS-1 payload snug in the cargo bay. The Principal Investigators and their teams were in complete communication with the payload and the Orbiter crew from the Payload Operations Control Center. An arcing problem in the spectrometer drive system prevented the Naval Research Laboratory team from obtaining data except at one wavelength, and the solar flare polarimeter did not get a large enough solar flare, but that was the luck of the draw. In all other respects, the mission was a complete success. The plasma team and the electron beam investigators were particularly pleased with their results, even though the observed glow caused by the oxygen in the atmosphere interacting with the Orbiter surface could pose a problem for future telescopes carried by the Orbiter.

From the Spacelab standpoint, the mission was another resounding success. A last-minute change of landing site to White Sands because of weather problems at Edwards added an extra degree of excitement to this mission. The Spacelab pallet and support systems had performed flawlessly. In terms of the validity of the procedure for pallet processing off-site from KSC, it apeared that this mission would probably prove to be an anomaly in the program. The die had already been cast and major components of the Spacelab would probably never again leave the confines of KSC for payload preparation.

PAYLOAD OPERATIONS CONTROL CENTER

The discussion above of the OSS-1 payload alludes to the support provided by the Payload Operations Control Center (POCC) at JSC. Plans for this appendage to the Mission Control Center were initiated in 1977–1978 under the sponsorship of Chet Lee's STS Operations Office at Headquarters. In late 1980, the responsibility for development was transferred from Lee's organization, now focused on STS utilization under the Office of Space Transportation Operations and its Associate Administrator Stan Weiss, to my Spacelab Program Office, since Spacelab would provide the major challenge to this new facility. Its purpose was to provide a single location where Principal Investigators and their support teams could interact with their instruments on board the Orbiter and with the onboard crew during a mission. There had been many arguments during the formative phase of planning for the POCC concerning the number of such centers needed and their location, but as with many such decisions, a single installation was decided as the cheapest approach, and JSC was selected because of the capability and space already existing in the Mission Control Center.

Within the Spacelab Program Office, John Moye was given overall program responsibility for the POCC and would work with Johnny Parker and Jim Mager at JSC. The initial goal was to provide a facility from which up to 21 experimenters could simultaneously operate, command, and control instruments on board the Spacelab and monitor the results. Each experimenter would have a display terminal on which a limited number of real-time experiment parameters could be displayed. Approximately 50 percent of POCC capability was to be available for use during the orbital flight tests.

JSC's initial proposal was to build the new facility for $18.5 million. This was quickly reduced to a $15-million limit by Headquarters. Working with the MSFC and KSC Spacelab teams, requirements were established and plans agreed for the purchase of additional Spacelab high-data-rate recorders to use within the facility. The POCC would consist of a payload control room where the Payload Operations Director and the support team would be located and a series of six or more user support rooms in which users could bring their ground support equipment and which would be provided with display terminals and other equipment for interfacing with the Orbiter and its payloads (fig. 111 and 112). A customer support room was also provided as a place for the Payload Mission Manager and the Spacelab Program Manager to monitor overall activities during the mission and interact with the Flight Director and POCC. The focus was to provide users with housekeeping data in order to know the general health and well-being of their equipment, rather than quick-look analysis on scientific data. With planned data rates as high as 50 megabits per second, reduction of scientific data would, for the most part, be handled by the Goddard Spacelab Data Processing Facility. In some cases, however, scientific data could be taken from the high-rate demultiplexer and channeled directly to the user's equipment. Other essential data to the user such as Orbiter location and altitude could be provided by the missions operations computer of the Mission Control Center.

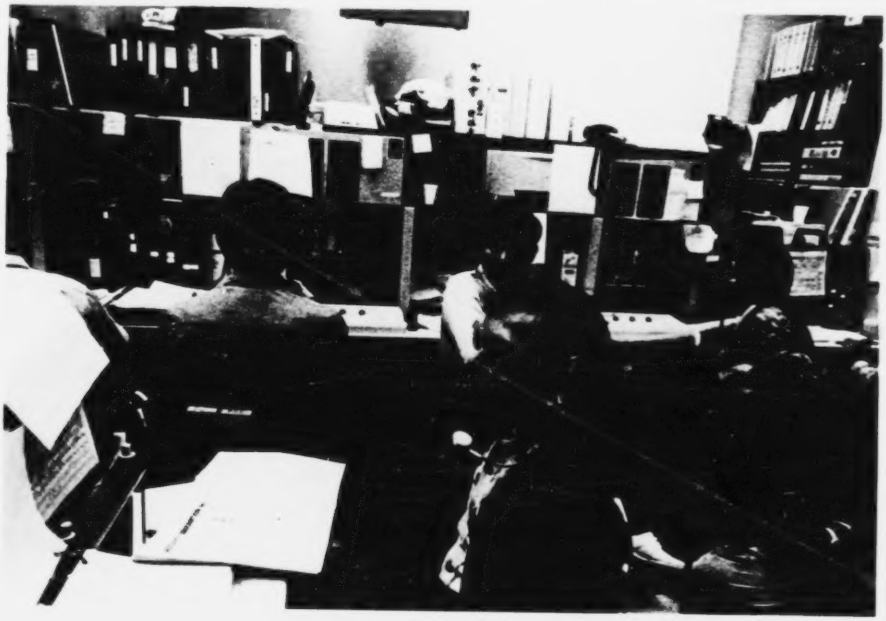
Figure 111. The payload control room in the Payload Operations Control Center at Johnson Space Center during the Spacelab 1 mission. Backup Payload Specialists Michael Lampton (seated at center) and Wubbo Ockels (above Lampton's shoulder) are seen conferring in the foreground.

The major problems in readying the POCC for support of the early missions were in handling the very high data rates, getting switches to operate reliably under those conditions, and finding room for the very large number of users scheduled to fly instruments on the Spacelab 1 mission. It was generally agreed that if the POCC could support that mission, it could support any Spacelab mission. As shown in chapter 11, the POCC was readied in time and did provide outstanding support to the Spacelab 1 mission.

TRACKING AND DATA RELAY SATELLITE SYSTEM

The important decision by NASA to sponsor industry development and leaseback of the TDRSS for communicating with orbiting spacecraft was to impact the Spacelab program in a number of ways. From the first days of manned space flight in the Mercury and Gemini programs though Skylab and the Apollo-Soyuz Test Flight, a series of ground-based tracking stations located around the world permitted tracking of the manned spacecraft, provided voice links with the onboard

Figure 112. A typical payload user support room in the Johnson Payload Operations Control Center showing crowded conditions for the Principal Investigators during the Spacelab 1 mission.



crews, and permitted data dumps as the spacecraft passed over the ground stations. The terms AOS (acquisition of signal) and LOS (loss of signal) used by the JSC Mission Control Center communicators became common phrases to those who followed the manned missions as we awaited brief glimpses of life on board the vehicles and crucial reports on the well-being of the support systems and the overall mission. As Earth-orbiting missions became longer in duration and higher in inclination, the periods of silence became frustratingly long—in some cases the orbiting vehicle did not pass within communication range of the tracking stations for several orbits in succession. Additional ground stations and tracking ships were used to fill these gaps, but it was impossible to cover the globe.

The proposed TDRSS would replace most of the ground-tracking stations with two satellites at synchronous equatorial orbit (22 000 miles altitude), one over the Atlantic Ocean and one over the Pacific. These satellites would be capable of tracking the Shuttle Orbiter over most of its orbital periods (three satellites would have been required for 100 percent coverage). The satellites would also be able to relay scientific and housekeeping data from the Orbiter or other satellites to a ground station at White Sands, at rates as high as 200 megabits per second. They would also provide for commands to be relayed to the Orbiter from the ground control center at JSC or elsewhere via White Sands.

You may recall that when the Spacelab agreement was signed, Spacelab was expected to fly on the first operational flight of the Shuttle. Thus, if the original schedule of six orbital test flights had been carried out, Spacelab would have been scheduled for the seventh mission. As the TDRSS program proceeded, however, the satellite became too heavy to be launched by any of the available expendable launch vehicles. The decision was made to use the Shuttle for carrying the satellite to low Earth orbit and to use the Air Force-developed interim upper stage (IUS) to boost the satellite to its geostationary location. It was felt that there should be two relay satellites in place before the first dedicated Spacelab mission to provide data return for at least 80 percent of the mission. A further complication was the requirement for several months' wait after putting the first satellite in orbit before launching the second and to have the second in orbit for several months to assure that the total system was checked out properly before it supported a mission as complicated and important as Spacelab 1. Thus, although the number of orbital test flights was reduced to four, the introduction of other requirements soon made it evident that the earliest mission on which the Spacelab would fly was the tenth Shuttle mission. This was a major disappointment to the Spacelab team, particularly the Europeans, who were finding it difficult to maintain support for the program in view of its many problems, its escalating costs, and what seemed to be a never-ending commitment to provide support to the first two Spacelab missions. Numerous problems were encountered in the development of the Tracking and Data Relay Satellite System, but for the purpose of this story, the most significant one after the decision was made to fly on the Shuttle was the failure of the IUS rocket motor during the launch of the first satellite in April 1983 (on STS-6). As a result, the relay satellite found itself in an elliptical orbit with little hope of achieving its mission objectives. The support team did not give up, however, and gradually nursed the satellite to its orbital position after a long series of firings of the satellite thrusters which were intended to provide stationkeeping once in place. Any hopes of launching the second satellite were abandoned until the failure of the boost stage could be understood and corrective action taken. Now the question was, should Spacelab 1 be flown with only a single relay satellite in place, or should it be delayed until the two-satellite system was ready? The discussion of operating Spacelab 1 with a single relay satellite had been discussed previously as a result of other problems, and the payload team had always insisted that two satellites were essential to conduct a meaningful mission. This was a difficult decision, as emotional and political as it was technical. Eventually it was decided that the mission should be conducted with the single relay satellite. A number of fingers would be crossed, and in some cases reflights of certain instruments were promised, but in general it was felt that a worthwhile mission could be conducted. Unfortunately, by the time of the Spacelab 1 mission, more bad news about TDRSS would surface, and, later, in the 1986 *Challenger* disaster, the second satellite would be destroyed.

SPACELAB DATA PROCESSING FACILITY

In order to provide an adaptable and reliable facility to accept and process the voluminous data streams generated by the Spacelab mission, a Spacelab Data Processing Facility was developed at Goddard Space Flight Center. The Spacelab data network actually begins with the onboard high-rate multiplexer, which gathers data for transmission to the Tracking and Data Relay Satellite System through the Shuttle K-band signal processor. The TDRSS/Domsat (domestic satellite) link then relays the data to GSFC where they are captured and processed by the data facility. The facility had to be built to handle K-band channels 2 and 3 digital data at a rate of up to 2 megabits per second for channel 2 and at a rate of 2 to 50 megabits per second for channel 3. Analog data must also be captured at a rate of 4.2 megahertz. The facility was divided into two major functional elements: the Spacelab input processing system (SIPS) and the Spacelab output processing system (SOPS) (fig. 113). The input processing system demultiplexes, synchronizes, time tags, quality checks, accounts for the data, and formats the data into computer-compatible tapes. The output processing system then edits, time orders, quality checks, blocks, formats for distribution, and records the processed data onto tapes for shipment to the users. Audio and analog data products generated in the input processing system are output directly to users.

In providing these critical mission support functions, the Data Processing Facility must work closely with the other NASA centers involved in the conduct of the Spacelab mission. For prelaunch verification, KSC provides test data for premission processing and shipment to users. MSFC, which had mission management responsibilities for the early Spacelab missions, levies project requirements on the Data Processing Facility and supplies premission products essential to specific mission support. JSC and MSFC coordinate real-time mission support that includes data

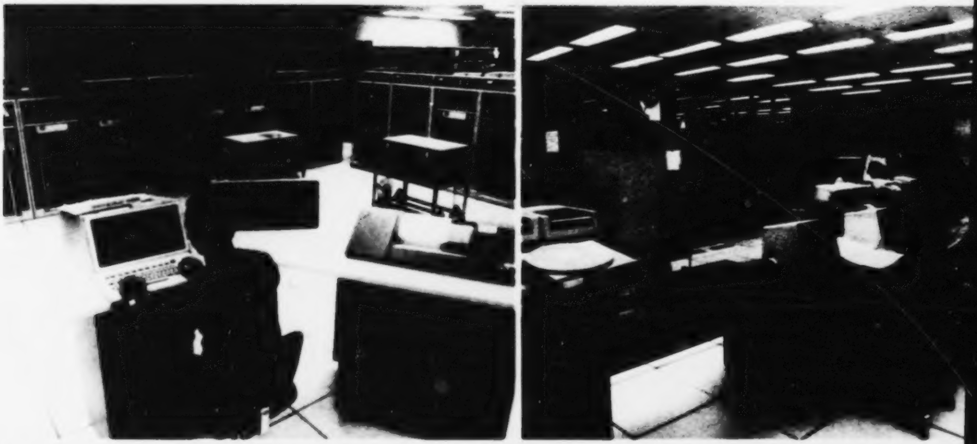


Figure 113. Two views of the Spacelab Data Processing Facility at Goddard Space Flight Center. The Spacelab output processing system (SOPS) is shown on the left; the Spacelab input processing system (SIPS) is on the right.

quality monitoring and updating of the nominal timeline. After the mission is completed, JSC also supplies Spacelab and Orbiter ancillary data.

For the users, the Spacelab Data Processing Facility offers a staggering variety of raw and processed data. Twelve different types of data tapes can be shipped: audio, analog, instrumentation, high-density, experiment, input/output, quality control and accounting, experiment channel, input/output channel, ancillary, postmission ancillary, and Orbiter ancillary. After a late start in planning, the Goddard team came through with flying colors in readying the facility for the Spacelab 1 mission. Processed data would be available from most missions within 2 months of the flight time. This provided a formidable tool for the Spacelab users, and it was on these data that the ultimate value of the Spacelab missions would depend.

PROCESSING FOR THE SPACELAB 1 MISSION

When the first flight unit arrived at KSC in December 1981, the launch of the Spacelab 1 mission was scheduled for September 30, 1983, less than 2 years away. After a post-delivery inspection, the racks, module floors, and one pallet were delivered to the Level IV stands for staging and for installation of the Spacelab 1 experiments. This was to be a joint U.S./European payload and some of the racks had remained in West Germany for installation of European experiments. A secondary structure for the Spacelab 1 pallet had also been assembled in West Germany for the integration of the European complement of instruments for the pallet. After the racks, floors, and pallet were staged with the proper harness, plumbing, and subsystem boxes, the KSC in-house team under Bill Jewell began installation of the U.S. experiments. Later, when these instruments were joined by the European-provided instruments, each experiment and the integrated chain were checked out to ensure proper interfacing with the Spacelab. A mission sequence test was then conducted to verify the timeline and data acquisition and hardware/software interfaces (fig. 114).

In the meantime, the core segment of the module was mounted in a Spacelab Level III/II workstand and integration of the verification flight instrumentation was begun by the NASA/MDTSCO integration team. Some 264 environmental, mechanical, and electrical sensors and the associated control, monitoring, and recording equipment had to be installed for the verification flight tests. In addition, all fluid lines, gas lines, structural seals, and shell penetrations were checked for leakage. The ground support equipment was then connected to the core segment and the module subsystem verification test conducted from July to September 1982. Most of the problems uncovered in this test were found in the command and data management subsystem, resulting in a return to Europe of several major components for repair or modification. This was done expeditiously, thanks to the ESA/ERNO resident team at KSC under Alan Thirkettle, and the equipment was returned to KSC and reintegrated by the first week of January 1983. Rechecking disclosed some new problems which were quickly solved, and the Spacelab was ready for the marriage of the experiment train with the module. This being the first time a fully integrated train was installed in the module, there were the inevitable structural distortions and some cable rerouting was necessary. Then the aft end cone was mounted to close up the module, and the pallet was put into place to complete the flight configuration (fig. 115).

Once the Spacelab was assembled, it was again necessary to check fluid lines and to balance the air flow to the racks before the Spacelab 1 system test could be conducted from January to March 1983, verifying the internal interfaces between the subsystem and the experiment train, including the pallet. The system test revealed technical problems in only two components, the subsystem power distribution box and the data display unit, which were quickly replaced.

Now it was time to power up the experiments and verify the total system in a mission sequence test designed to perform slices of the expected flight profile. This test, performed in March and April 1983, simulated about 79 hours of the planned 215-hour flight, with the Orbiter simulated by ground support equipment and the high-data-rate recording and playback being demonstrated. The test was remarkably successful, with more than 70 experiments, the Spacelab subsystems, and the control software working well together (fig. 116). Of course there were some significant problems, but these were quickly corrected by software changes and experiment and equipment repairs, and by May 1983 the transfer tunnel had been integrated to the module and its interfaces verified.

The next test was the much-discussed CITE test (fig. 117). On May 18, 1983, Spacelab was moved to the CITE stand for a higher fidelity simulation of the Orbiter interface and use of the KSC launch processing system. During this test, the data link to the payload operations Control Center at JSC was simulated using a domestic satellite in place of the TDRSS. The CITE test was remarkably problem-free and the

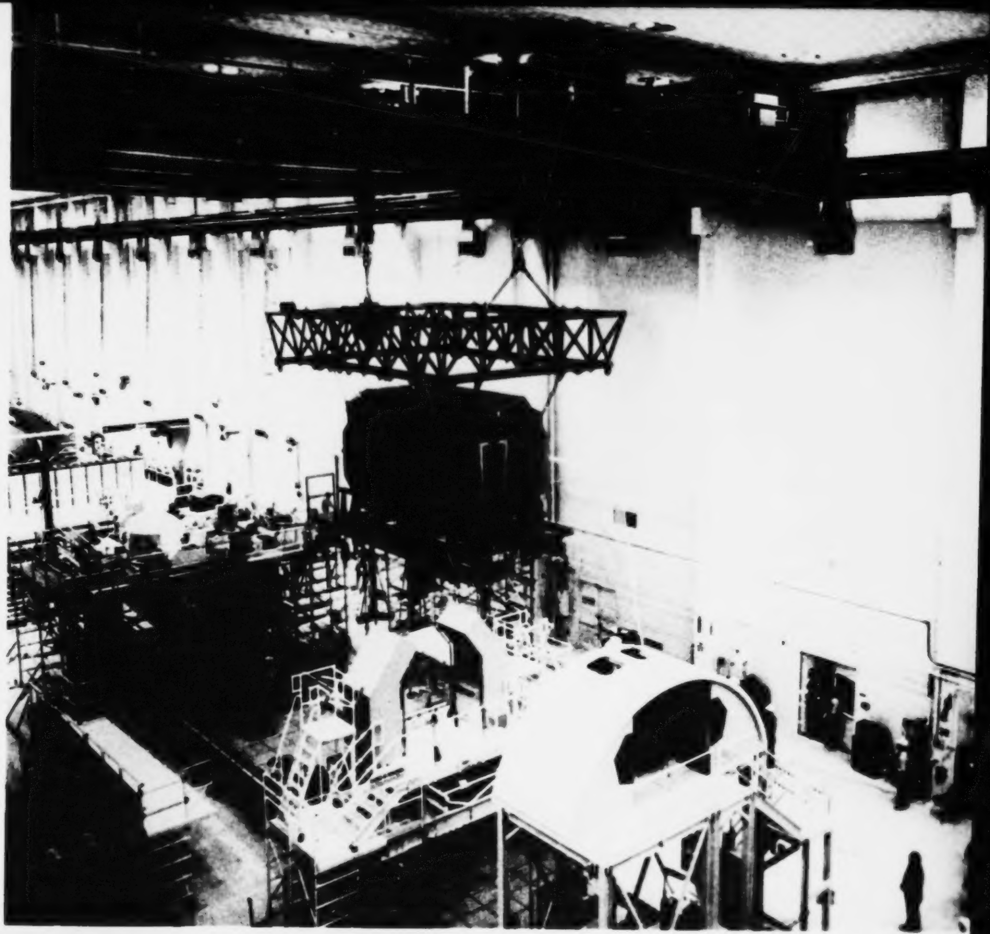


Figure 114. The Spacelab 1 experiment racks being removed from the Level IV workstand in the Operations and Checkout Building after installation of experiments. Note the pallet with the assembled payload to the left of the workstand.

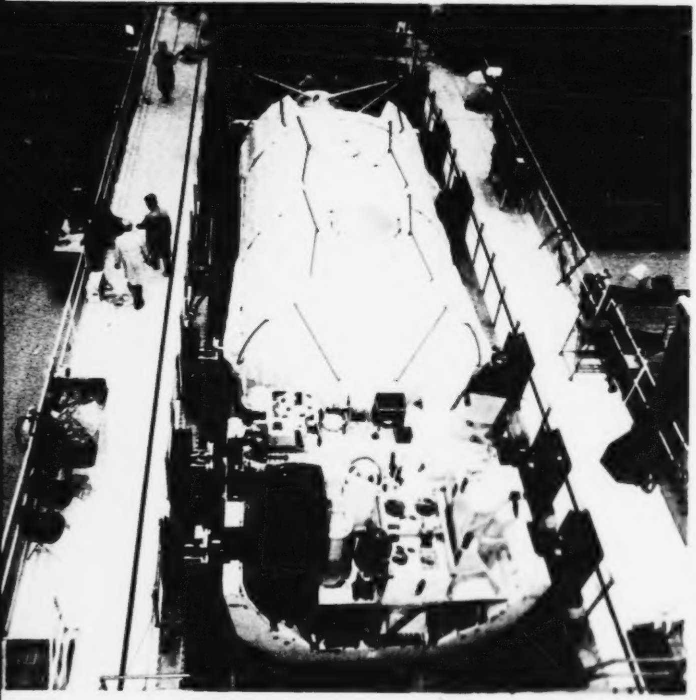


Figure 115. The module and pallet assembled for the Spacelab 1 mission in the Level III/II workstand at Kennedy Space Center.

Figure 116. Spacelab 1 crew members (shown looking up, left to right) Byron Lichtenberg, Owen Garriott, and Ulf Merbold assist in the checkout of the module at Kennedy Space Center.

POCC-to-Spacelab link test verified the command link from JSC to the Spacelab and the correct reception of telemetry from the Spacelab at JSC. The data display unit again had to be replaced and the 6-hour offgassing test under continuous power revealed traces of a contaminant, but this would be solved by operating the tunnel fan and scrubber to remove the contaminant. A module leak test demonstrated a pressure decay only one-eighth the allowable rate.

The planned testing of Spacelab in the O&C Building was now completed, ahead of schedule, but in the meantime the TDRSS had encountered its launch failure and it was evident that two relay satellites would not be ready to support the September 30 launch. The launch (now scheduled on STS-9) was slipped to October 28 in the hopes that the one relay satellite would be operational at that time.

On August 15 the Spacelab was placed in the payload canister, transferred to the Orbiter Processing Facility, and installed in the Orbiter *Columbia* the next day (figures 118–120). Three specific and important tests were conducted during the next month: the Spacelab/Orbiter interface test to verify power, signal, computer-to-computer, hardware/software and fluid/gas interfaces; the Spacelab/tunnel/orbiter interface test to verify tunnel lighting, air flow, and VFI sensors; and the end-to-end command/data link test of the Spacelab/Orbiter/TDRSS/White Sands/Domsat/JSC/GSFC link. Again the few problems encountered were quickly solved and on September 20 the Orbiter cargo bay doors were closed. The Orbiter was moved to the Vertical Assembly Building on September 23, and on September 28 the Shuttle assembly was rolled out to the launch pad.

Two countdown tests were conducted on the pad, one with the flight crew (pro-

Figure 117. Spacelab 1 module and pallet mounted in the CITE stand for final interface testing in the Operations and Checkout Building.

pellant tanks empty), and one with all propellant loaded (using ground personnel). The Spacelab was powered up for both tests and performed flawlessly. A new problem was introduced now because of a problem found in the solid rocket motor ablative nozzle liners in the previous launch (STS-8). After an agonizing assessment, the Shuttle was rolled back to the Vertical Assembly Building and destacked so that a replacement nozzle could be installed in one of the solid rocket boosters. During this period several major problems in the Orbiter also had to be resolved.

From the Spacelab viewpoint, this delay required servicing and calibration of the experiments and generation of new flight software corresponding to the revised flight date, which was finally chosen to be November 28. The Orbiter was returned to the Vertical Assembly Building for a second time on November 4, and the Shuttle was rolled out again to the pad on November 8. The Ku-band antenna deployment assembly was replaced and Spacelab was powered up to generate 48 megabits per second of multiplexed data to be sent to the Ku-band transmitter and then by a fiber-optics link to the O&C Building to verify zero-error transmission. A second activation of the Spacelab was necessary to enable the revised flight timeline software to be loaded into the mass memory unit and verified. At last, it appeared that Spacelab was ready to go.

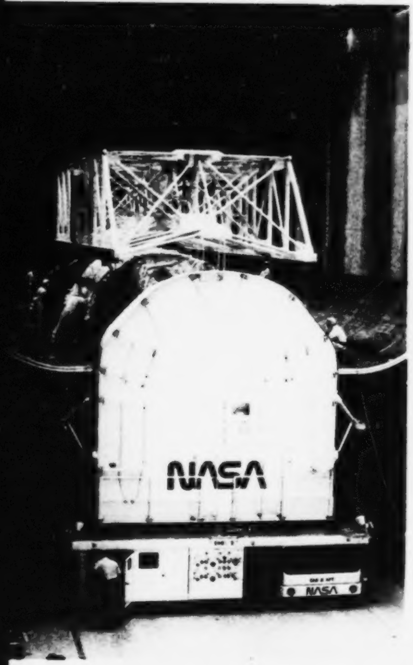


Figure 118. The Spacelab 1 module and pallet placed in the payload canister for transfer to the Orbiter Processing Facility at Kennedy Space Center.

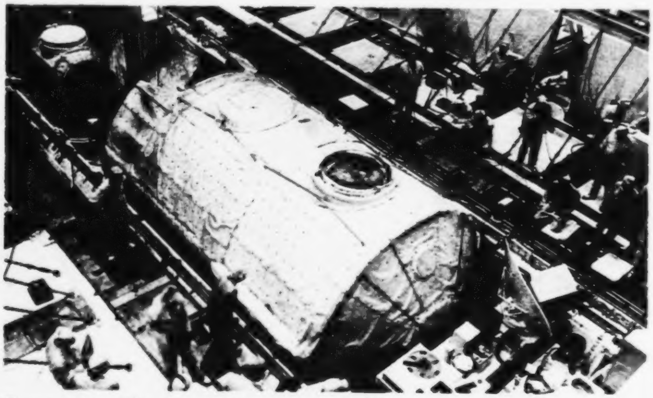


Figure 119. The Spacelab 1 module and pallet are installed in the Orbiter *Columbia* at the Orbiter Processing Facility.

Figure 120. The tunnel and tunnel adapter (note the open hatch on the left) are installed in the forward portion of the *Columbia* cargo bay.

CLEANING UP THE PAPERWORK

Although it was obvious that Spacelab was nearing readiness for flight, NASA's insatiable appetite for documentation would not be satisfied until all the i's had been dotted and all the t's crossed. A formidable obstacle path of reviews had to be overcome during the final 2 years before the launch of Spacelab could be permitted.

DESIGN CERTIFICATION REVIEW

During 1979-1980, there had been a number of discussions concerning the possible need for a NASA certification review following the acceptance reviews at ERNO and the receipt of the Spacelab hardware at KSC. In November 1980, MSFC undertook a reassessment of the Spacelab reviews conducted in the past and those planned for the remainder of the program. Although it was recognized that there would be several operational reviews to assure that the Spacelab, the Shuttle, and the operational support systems were ready for the Spacelab 1 mission, the issue was whether NASA should conduct a quasi-independent evaluation of the Spacelab to assure that the designed hardware and software would support its intended application. Such reviews, at the Headquarters level, had become a standard requirement in the previous manned programs such as Apollo, Skylab, and the Shuttle.

It was agreed that NASA would conduct a Design Certification Review, with support from ESA and its prime contractor, ERNO. The objectives would be to review the performance and design requirements; to determine that design configurations satisfied the requirements; to review substantiating data verifying that the requirements had been met; to review the major problems encountered during design, manufacturing, and verification and the corrective action taken; and to establish the remaining effort necessary to certify flightworthiness. The review documentation was assembled by the McDonnell Douglas Technical Services Company from March to October 1982. In addition to preparation of the documents, MDTSCO identified hundreds of discrepancies needing assessment during the review. Documentation review, assessment, and certification was conducted during November by eight subsystem/discipline teams made up of personnel from NASA, ESA, MDTSCO, and ERNO. In order to provide an independent assessment, a high percentage of individuals involved in this review were from outside the program; therefore there were many "show and tell" presentations in order to bring everybody up to speed. Following the team reviews, a preboard was conducted at MSFC under the chairmanship of James R. Thompson, Jr. on December 1 and 2, and an MSFC board was chaired by Center Director Bill Lucas on December 14.

The final presentations and NASA Headquarters board review were held on

January 13, 1983. Headquarters had again been reorganized by this time and Lt. Gen. James Abrahamson was the Associate Administrator of the reconstituted Space Transportation System Office, which again included the Spacelab Program Division, so he chaired the board. In addition to the Spacelab Directors (Bignier and Harrington) and the Spacelab Managers (Pfeiffer and Thomas), the Board included the Center Directors from MSFC (Lucas), KSC (Smith), and JSC (now Gerry Griffin). Also included on the board were representatives from the payload side (Mike Sander and Bill Raney), the Chief Engineer (Stan Weiss) and his Deputy (Haggai Cohen), Abrahamson's Deputy (Mike Weeks), and Hans Hoffman, long-time leader of the ERNO team. To complete the group and bring in their special expertise, John Yardley and Walt Williams had been brought back from their jobs outside NASA (fig. 121).

Two aspects of the Design Certification Review (DCR) are worthy of special mention. First, the Marshall and MDTSCO teams did a remarkably comprehensive and disciplined job of preparation for the various teams, preboards, and center and

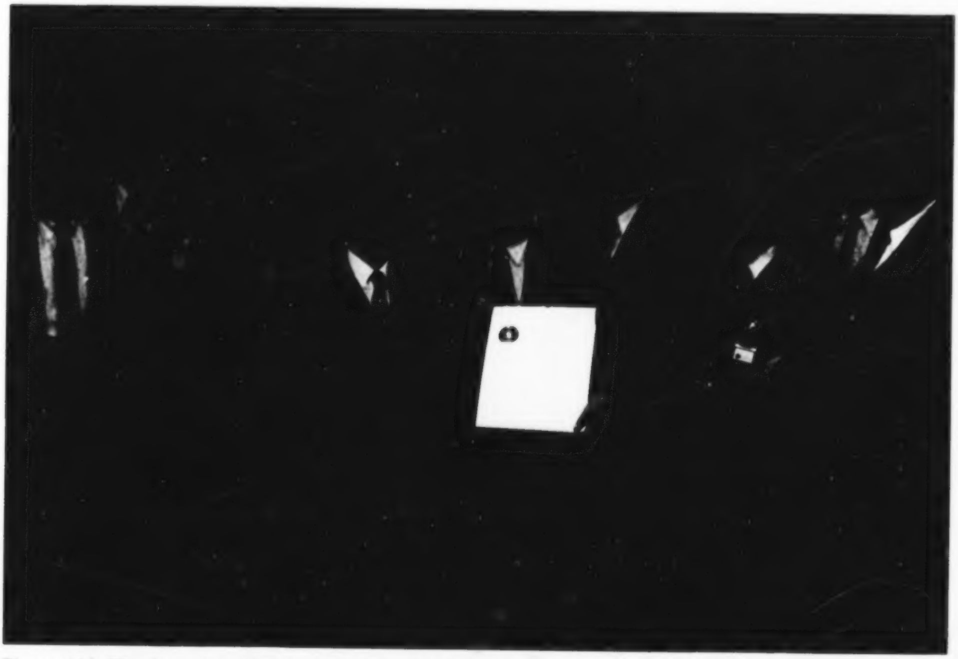


Figure 121. The Spacelab Headquarters Board for the Design Certification Review. Left to right, Stan Weiss, Dick Smith, Mike Weeks, Gerry Griffin, John Yardley, Walt Williams, Jim Harrington, Hans Hoffmann, Haggai Cohen, Michel Bignier, Bob Pfeiffer, James Abrahamson, Mike Sander, John Thomas, Bill Raney, and Bill Lucas.

Headquarters board meetings. Second, the reports and presentations were exemplary to such an extent that Mike Weeks stated that he had never before participated in such a well-prepared review, and "on a scale of one to ten, John Thomas and his DCR team scored an eleven!." Ray Tanner and Bobby Jackson on the NASA side and Bob Brotherton and Jack James on the MDTSCO side, among many others, made this happen. As a result of this high evaluation, a very important hidden agenda for the DCR had clearly been accomplished, which was to demonstrate that in-depth technical knowledge of the Spacelab systems had been transferred from Europe to the U.S.

Following an overview of the program, the board reviewed the systems integration and operations status, then the specific subsystem/discipline reports, and the materials, safety, reliability and quality assurance considerations. Finally, the board gave formal certification to the Spacelab. Another major milestone had been passed.

CARGO INTEGRATION REVIEW

The first operational review to be faced by Spacelab 1 was the Cargo Integration Review for the STS-9 mission conducted at JSC on June 10, 1982. The purpose of this review was to determine whether the payload requirements could be met and whether the cargo complement could be accommodated within Space Transportation System flight and ground capabilities. The review board was chaired by Glynn Lunney, now the Shuttle Program Manager, and included membership from JSC, KSC, MSFC, GSFC, Headquarters, and Rockwell. Presentations were made to the board covering cargo familiarization, flight planning, flight operations support, training, engineering compatibility with the Orbiter, engineering compatibility with the Spacelab, interface verification, ground operations, safety, and schedules.

Highlights of the Cargo Integration Review were the discussions of the constraints on the launch window, performance of the Shuttle, early activation of the Spacelab, readiness of the POCC, the addition of a cryo tankset for additional time on orbit, and high usage and reliability of the vernier thrusters. Although additional work items were identified with respect to these areas, the board concluded that the hardware, software, flight documentation, and flight activities would support the planned launch schedule of September 30, 1983. The first operational approval hurdle had been cleared.

INTEGRATION HARDWARE/SOFTWARE REVIEW

From December 6 to 9, 1982, the JSC Mission Integration Office under Leonard Nicholson conducted an STS-9 Integration Hardware/Software Review. Its purpose was to verify the compatibility of the integrating hardware and software design and Orbiter capability against the cargo requirements for STS-9. Review teams from the various disciplines met in working groups on December 6-8 to review the drawings and documentation, and on December 9 a board was convened under the chairmanship of Nicholson's deputy, Larry Williams, for the team to present its findings and submit discrepancy notices. A total of 99 discrepancy notices had been generated of which 18 were presented to the board for disposition and information. Seventy-eight open discrepancy notices would be tracked on a regular basis and closed out before the Flight Readiness Review. Although a number of problems surfaced in this review and six actions were assigned, the overall findings were positive, verifying that the Orbiter payload accommodations design and integration hardware and software products would meet the cargo requirements and were compatible to support the STS-9 launch schedule.

FLIGHT OPERATIONS REVIEW

On June 17, 1983, Glynn Lunney, now manager of the National Space Transportation Systems program at JSC, issued the plan for the STS-9 Flight Operations Review. This was to be a formal review of flight operations products by the STS operations program managers and the customers (in this case the Spacelab and its payload). The intent was to baseline the operations documentation through this management evaluation of the translation of payload requirements into implementation plans and activities.

A complete data package, including the crew activity plan, selected portions of the flight data file, training and simulation plans, flight rules, and launch commit criteria would be available on June 22. Organizations invited to participate in the review were the Space Operations, Mission Operations, Flight Crew Operations, and Mission Support Directorates from JSC, the Spacelab Program and Spacelab Payload Program Offices from MSFC, and ESA. In the usual fashion, participants would prepare discrepancy notices and the Mission Operations Directorate would convene team meetings to review the discrepancy notices on June 28.

On June 30, 1983, Lunney chaired the Flight Operations Board meeting. The meeting began with a "walk-through" of the STS-9 flight operations. Presentations covered the crew activity plan, trajectory overview, flight data file, payload operations support, flight rules, Mission Control Center/POCC/network configuration and implementation, training summary, and MCC Spacelab systems support.

In every area there were new bridges to cross because of the very nature of the STS-9 mission with its Spacelab payload. For the first time, the flight crew would be divided into two teams for round-the-clock operations. John Young (Commander), Bob Parker (Mission Specialist), and Ulf Merbold (Payload Specialist) would constitute the Red Team which would focus its activities on material science, Earth operations, and ESA life sciences experiments. Brewster Shaw (Pilot), Owen Garriott (Mission Specialist), and Byron Lichtenberg (Payload Specialist) would make up the Blue Team, which would concentrate on plasma physics, atmospheric physics, and NASA life sciences experiments. Many attitude maneuvers would be required during the course of the mission, and the incorporation of the fifth energy kit in the Orbiter (after years of argument that this was too difficult) had provided electrical energy for the longest mission to date: 9 days. JSC would operate as host for the Spacelab 1 payload, which would be operated and controlled by the science crew and the MSFC payload operations team located in the POCC at JSC. Providing space within the POCC for the scientists of the 38 experiment facilities on board Spacelab 1 would be a difficult challenge. Flight rules for this very complicated mission with Spacelab in its first flight and the conflicting desires for verification flight test data and scientific data were also difficult. The scientific air lock with its potential requirement of EVA for emergency jettisoning added another degree of complexity. In the communications area, the TDRSS and the links to White Sands and Goddard would receive their first test under very demanding flight conditions. Just to make that situation more interesting, data would also be relayed to the German Flight Operations Center in Oberpfaffenhofen. The training plan for the period between the Flight Operations Review and the STS-9 launch date was crowded with simulations to verify the communications links and training of both flight and ground crews. Finally, possible systems problems within the Spacelab resulted in plans for providing supporting data within the JSC Mission Control Center and voice and monitoring loops to the Huntsville Operations Support Center at MSFC.

After completion of the flight operations "walk-through," the board heard concluding presentations from teams in the areas of training, flight planning, flight operations support, and flight rules. Although a number of issues were highlighted, none appeared to be sufficiently serious to delay the planned September 30 launch date. It appeared that JSC was ready for Spacelab 1.

CARGO READINESS REVIEW

Focus on the review process now switched to KSC where, on July 25, 1983, John Neilon, Manager of the Cargo Projects Office, chaired the meeting of the Cargo Readiness Review Board. The purpose of this review was to verify the readiness of Spacelab 1 and supporting elements for on-line integration with the Orbiter, verify the readiness of the Orbiter to receive Spacelab 1, and review the KSC cargo integration assessment from cargo transfer to the Orbiter through mission completion, including identification of any major problems, constraints, or workarounds. The board was made up of the senior KSC Directors plus Bignier, Harrington, and Thomas representing the Spacelab program and Mary Jo Smith, the Spacelab 1 Payload Program Manager, and Harry Craft, the Payload Mission Manager.

The milestone events in the Spacelab program were reviewed, and it was reported that all objectives were accomplished in three key tests at KSC: the integrated systems test, the cargo/Orbiter interface test (CITE), and the closed loop test from Spacelab to the MCC/POCC. The status of Spacelab program reports, waivers, and unexplained anomalies were then discussed in some detail, along with a description of all open work on the Spacelab. The major open item was the offgassing test, scheduled to be conducted the following day.

The board then considered the readiness of the Spacelab payload. Like the Spacelab itself, the payload had overcome thousands of problems and many reviews, both on the individual experiments as well as on the integrated payload. The reviews included were requirements, initial design, final design and operations, ground operations, acceptance, flight operation, integration readiness, and certification. Like the Spacelab, the payload had satisfactorily completed its major KSC tests: integrated testing with the Spacelab, simulated Orbiter interface testing, and closed loop tests. Only a very few open items remained and these did not appear to pose any constraint for the start of Orbiter/Spacelab integration.

On the Shuttle side, an even shorter list of open items was presented: the Shuttle would be ready for Spacelab installation by August 2. In summary, the board concluded that upon cancellation of the open work presently scheduled, the integrated Spacelab would be in proper configuration and performing to specifications. The Spacelab systems-to-experiment compatibility had been demonstrated and the cargo-to-Orbiter interfaces verified. The Spacelab ground and flight software had been verified and Spacelab was on schedule to move to the Orbiter Processing Facility.

SPACELAB DUTY-FREE ENTRY

A paper exercise of a completely different nature was this attempt to avoid the payment of customs duties on the Spacelab being purchased from ESA. Bob Wojtal of the NASA General Counsel Office devoted a considerable portion of his working days to this thorny issue and deserves much of the credit for its successful outcome. On January 16, 1979, NASA made application to the Bureau of Customs (later the Customs Service) of the Treasury Department for duty-free entry of the Spacelab from Europe (and the remote manipulator system from Canada) under the Educational, Scientific, and Cultural Materials Importation Act of 1966. In a bureaucratic tangle beyond reason, the Bureau of Customs was obliged to ask the Department of Commerce to make the determination that the Spacelab was a scientific instrument that did not have commercial value. Unfortunately, although Customs agreed that it was a scientific instrument within the Act, the Department of Commerce concluded that Spacelab was not a scientific instrument within the standards of the statute. Furthermore, the Statutory Import Program Staff Director of the Department of Commerce argued that the Spacelab could have been built in the U.S. and that domestic manufacturers would have been willing and able to manufacture the Spacelab. The fact that the Spacelab was a result of international negotiations, diplomatic exchanges, and European funding had no impact on his opinions or conclusions.

As a result, it appeared that NASA would have to devote $19 million of its appropriated funds to pay custom duties for the importation of Spacelab elements and the remote manipulator system which were to be purchased. Apparently customs duty on the Spacelab engineering model and first flight unit could be avoided because the Memorandum of Understanding was mute about ownership and, in this case, it was to our advantage to let ESA retain ownership. ESA had been considering transferring title to NASA, probably to avoid long-term responsibility for sustaining engineering or in the case of third-party liability suits. Even in this situation, it appeared NASA could avoid the customs duties by accepting the first units as gifts, in which case duty is not required.

The problem remained as far as the second flight unit and subsequent purchases were concerned. It appeared that funds would be transferred from one Treasury account to another, with no perceptible advantage given to U.S. manufacturers and no new increase in funds benefiting the Treasury. After repeated efforts to overcome this senseless bureaucratic nightmare, a new approach was taken. A bill was introduced in Congress to permit the import of space materials certified by NASA without paying customs duties. This bill, eventually approved as a part of H.R. 4566 to become P.L. 97-446, stated: "the return of materials from space by NASA shall not be considered an importation, and an entry of such materials shall not be required." It thus exempted "articles imported to be launched into space under launch service agreements with NASA." NASA was given the authority to certify "the materials to be imported to be launched into space, spare parts, or necessary and unique associated support equipment for use in connection with a launch into space." This latter provision was essential for NASA to determine appropriate ground support equipment to be included. On May 17, 1983, the NASA Administrator signed a blanket certificate for the duty-free entry of Spacelab and remote manipulator system materials. A subsequent policy was published in the *Federal Register* for NASA to administer the new law, and a very difficult problem had been solved.

FINAL PERSONNEL CHANGES

Throughout earlier chapters I have chronicled the leadership roles of key personnel in the program, because in my opinion the success of Spacelab is due to the many outstanding individuals who guided the program down its many pathways to and through the early missions. As the time for flight neared, the changes continued. In August 1981, Jim Morrison, who had been the NASA European Representative in Paris for over 3 years, returned to NASA Headquarters and was replaced by Dick Barnes. Barnes had been a key member of the NASA Headquarters International Office staff for many years and had participated in many Spacelab decisions and meetings since the first negotiations between the U.S. and Europe. He was a logical choice to continue the line of highly qualified and dedicated representatives from NASA to Europe. A parallel change was made in late 1983 by ESA when Ian Pryke, assistant to Wilf Mellors since August 1979, took over his mentor's role as head of ESA's Washington office.

The Local Project Managers for the various co-contractors of the European industrial consortium during the development phase are identified in chapter 7. As the program neared its climax, however, several changes occurred: at British Aerospace in 1981, Trevor Pinder replaced Basil Smith; at Dornier, Reinhard Schaefer (1980) and Peter Lautenbach (1982) followed Otto Mayer; at SENER, Manuel Valls replaced Jose Dorado in 1980; and at MATRA, Jean Baillovoine (1983), Jean-Claude Guillen (1984), and Philippe Delbey (1985) followed Francois Vignes. At ERNO, Project Manager Ants Kutzer turned the reins over to Jurgen Rosen in 1984 prior to the final development mission (Spacelab 2). A similar change was made at ESTEC after the Spacelab 1 mission when Bob Pfeiffer relinquished his position as ESA Spacelab Project Manager to Gert Altmann for the final phase of the development effort.

FLIGHT READINESS REVIEW

At last, the program was down to its final major review before the Spacelab 1 mission. The Flight Readiness Review is the *pièce de résistance* for any mission, the point in time when the responsible Program Directors, Center Directors, and Associate Administrators are convinced that everything is in readiness for the flight. It is then time to convince the Administrator and receive the final go-ahead.

On November 18, 1983, after the Shuttle had been rolled to the launch pad with its Spacelab payload for the second time, Gen. Abrahamson introduced the agenda and presenters for the STS-9 Flight Readiness Review to Administrator Beggs and Deputy Administrator Mark at NASA Headquarters. KSC, JSC, and MSFC were party to this teleconference and everyone was expecting a routine review and approval for the mission. JSC and MSFC mission operations representatives and various managers of the Shuttle program gave status reports on their readiness. These reports had become somewhat routine now that this was the ninth Shuttle mission, and their recommendations were accepted with a minimum of questions. Then it was time to consider the Shuttle cargo, in this case the Spacelab and its experiments. John Thomas, the Spacelab Program Manager, and Harry Craft, the Payload Mission Manager, had prepared presentations that traced the reviews and test steps which had been taken to assure that the Spacelab and its payload were ready for flight. These were, in essence, administrative presentations without any discussion of technical and operational problems encountered, solutions adopted, or waivers required. In the Headquarters conference room, the frustration building within both Beggs and Mark was obvious to all, as they reacted to what looked like a whitewash. Eventually they called a halt to the proceedings and sent the Spacelab team back for more information. Over the following weekend Mark met with Harrington in his office and, with Thomas on the phone to provide detailed technical answers, rummaged through the records of the Design Certification Review to satisfy his concerns about the adequacy of the test programs and the validity of the reviews.

On November 21, Thomas and Craft presented new summaries to the Administrator in which they highlighted the significant problems and resolutions within each major test during KSC's processing of the Spacelab. Unexplained discrepancies, significant exceptions, waivers, deviations, and hazards analyses also were addressed in some detail. In the case of the payload, discrepancies were identified at each level of integration, the tolerance of the mission to off-nominal situations was detailed, the results of the simulations were given, and the impact to payloads of the reduced TDRSS performance was explained. With these forthright presentations, the Administrator and Deputy Administrator were satisfied. At last, preparations for the launch could be completed.

Personal Reflections

The contrast in operations between the OSTA-1 and OSS-1 payloads was indeed interesting. It may be that the OSTA-1 payload handling approach was dictated as much by the time schedule as any other consideration, because when that program was started it appeared there would be little slack time in the schedule. Every decision was made, therefore, in terms of reducing the planned integration time. It is doubtful that JSC could have taken the pallet to Houston for integration of the experiments, even if that had been the desire.

Another consideration is that JSC had integrated experiments on manned spacecraft many times before and had utilized the facilities at KSC for this purpose. Goddard, on the other hand, was a center that was proud of its record in building automated satellites. It was comfortable with the technique of integrating a payload in its facilities at Greenbelt, Maryland, and then transporting the payload to KSC for final integration with the launch vehicle. The term "ship and shoot" is sometimes used to describe this procedure, although some people use this expression only if there will be little or no checkout of the payload at the launch site. It has been postulated that that technique will be used when and if Spacelab payloads are launched into polar orbit from the Vandenberg facility in California. That is, final checkout of the Spacelab and its payload would be accomplished in the O&C Building at KSC and the assembled system would be transported to Vandenberg for installation into the Shuttle and launch.

In any case, the OSS-1 payload was integrated to the pallet at Goddard. In talking to representatives of Goddard and KSC about the efficiency of this approach, I learned that the conclusions are directly related to the home base of the respondent. The Goddard people felt that the operation was very straightforward, not unlike their experience with unmanned satellites. They are accustomed to working with contractor-provided hardware and systems and know how to handle them. KSC representatives, on the other hand, stated their concerns about the kind of handling the pallet and its subsystems received while at Goddard. Did the team drill holes where they shouldn't have? Was the pallet improperly loaded? Where were the documents that detail this history and describe the procedures used? Goddard representatives responded that these were stupid questions, that they knew how to handle such hardware and did not need all the detailed paperwork that KSC requires. A typical problem encountered with the pallet at Goddard best illustrates this problem. While mounting a piece of equipment on one of the Orbiter-provided cold plates, a worker drilled through the cooling passages. These cold plates, manufactured by Hamilton Standard, are very delicate and covered with extremely thin sheets of metal. Normal procedure in the manned programs would have dictated scrapping this piece of hardware, but Goddard found a technician who could make a repair and it was subsequently pressure tested and used. Whether or not

KSC would have permitted this action is conjecture, but certainly not without an extensive test and review process. When the pallet and its Goddard payload moved to KSC, the shoe was on the other foot. Now Goddard people became the perfectionists, insisting that KSC not touch the payload. KSC continued to argue it should have that authority and must have adequate procedures developed by Goddard in order for the KSC team to do its job.

The final result might have been expected. Goddard will probably never again take a pallet to its facilities to assemble another pallet payload. Instead, Goddard has taken the approach of developing new mounting structures to satisfy its own Shuttle payload needs. These may be similar to the SPAS structure built by MBB, the MPESS structure built by Teledyne-Brown, or modifications or extrapolations of the "getaway special" (GAS) structures built at Goddard for attracting new customers to the Shuttle. Although Goddard representatives will argue that these structures better satisfy their payload needs, I am convinced that parochialism within NASA has again won out. Each center wants its own system and control of that system.

Development of the Payload Operations Control Center at JSC was a unique undertaking with political as well as technical overtones. Although the initial plan was to provide space for up to 21 investigators, Spacelab 1 was to house 38 instrument facilities and the materials science facility alone had upwards of 40 investigators. When one adds the MSFC Payload Mission Manager and his staff, and the MSFC Spacelab Program Manager and his staff, plus the JSC Payload Operations Director with his supporting POCC cadre, the total requirement of spaces and equipment would escalate dramatically. One of the first requirements was to add 20 tons of air-conditioning capability to the building.

The continuing battle for increased funding to meet the escalating needs of the POCC led to bad feelings all around. Although the working level continued to wrestle with its problems and eventually was able to satisfy most of the payload requirements, it was hinted that the JSC Director would be happy to get rid of this albatross. Whether this frustration resulted from ongoing intercenter warfare as the MSFC team argued for its payload requirements and placed a large MSFC banner in its POCC management room or whether the Director was looking forward to utilizing this area for Space Station purposes is anybody's guess. In any event, the planning for future Spacelab missions and the preponderance of payload activity eventually led to the decision that another POCC should be constructed at MSFC.

The Tracking and Data Relay Satellite System was plagued with problems from the beginning. George Low had been the moving force behind the decision to proceed with this system and felt that NASA needs could be met by a leased system developed in cooperation with private industry. Thus the system could be used by the private operator to meet other commercial needs during periods when it was not required to support NASA missions. TRW won the lucrative contract to build the satellites and encountered an abundance of problems with their design and development. In some cases it appeared that NASA did not have sufficient manpower overseeing this program. In addition to the TDRSS not being under the direct control of NASA, neither was its booster stage, which the Air Force was to develop as part of its share of the Space Transportation System. The combination of these circumstances and the technical problems encountered would prove to be a costly situation for NASA and a disappointing fact of life for the Spacelab program.

The debate about the adequacy of the minimal Orbiter/Spacelab interface testing at JSC went on for many years. John O'Loughlin, the JSC coordinator for Spacelab planning, was amazed that I held the line on this point, as he was convinced we were headed for serious trouble when the total Spacelab system first met a fully simulated Orbiter in the CITE test. O'Loughlin knew John Thomas supported the Headquarters approach, but sensed his nervousness about the point, so he bet Thomas a bottle of Jack Daniels whiskey that problems would surface during the CITE testing that would require a slip in the Spacelab 1 mission. Fortunately for the program, he was wrong, and John Thomas collected on the bet.

During the Spacelab processing at KSC, I was enjoying a few months of idle retirement and then 14 months in a completely different job as director of a church camp and retreat center in Northern Virginia. The change of pace was fun, but I missed my space activities and many good friends both in the U.S. and abroad. When the first launch of the Shuttle was scheduled, I eagerly drove to Florida for the long-anticipated event. The first attempt at a launch was scrubbed, unfortunately, and so I decided to take my wife to the O&C Building to look at the Spacelab hardware. How quickly one is forgotten. My NASA retirement badge wouldn't even get me past the guard to get near the O&C Building! Very much humbled, I turned away from KSC, but the seeds had been sown for me to renew my relationships with the space program. Perhaps something would come up.

The plethora of reviews in a program such as Spacelab has to be experienced to be fully appreciated. In most cases, the final board meetings are relatively meaningless affairs because all the serious issues have been addressed and resolved. There is also a screening process through the team and preboard stages that permits many issues, which might be of concern to the final board, to be buried. Occasionally a problem is so serious or has such a major programmatic impact that it can only be addressed by the top-level board. In the same manner, it is difficult for an outsider to come in at the time of a review and understand the details of the program in adequate measure to find substantive issues and make meaningful recommendations. On the other hand, sometimes these outsiders will bring fresh insight or experience from another program that is beneficial to this one. In summary, I must conclude that the NASA program review process is a good one, even though time consuming and expensive. The major benefit is in the discipline required to prepare the review documentation and in the strength of the technical teams that conduct the tedious review of the documents. In the Spacelab program, hundreds of people from government and industry participated in the various reviews. To these people I say a hearty thanks. Though most will go unrewarded and unrecognized, they can take satisfaction in knowing that without their contributions, Spacelab may have been a failure instead of an unmistakable success.

11

At Long Last-Spacelab Flies!

1983-1985

SPACELAB 1 MISSION

The final launch date of November 28, 1983 approached. Articles in various scientific, aerospace, and popular magazines gave the upcoming mission mixed reviews. Certainly it was recognized as the most ambitious Space Shuttle mission to date, characterized by the following "firsts":

- First flight of the European-built Spacelab
  (development cost approaching $1 billion)
- First flight of non-career astronauts
  (Payload Specialists Merbold and Lichtenberg)
- First flight on a NASA mission of a non-American
  (Merbold, a German)
- Longest Shuttle mission
  (planned for 9 days)
- Largest Shuttle crew
  (Commander, Pilot, two Mission Specialists, two Payload Specialists)
- Two shifts for 24-hour operations
- First operational use of the Tracking and Data Relay Satellite System

Time magazine described the Spacelab as an outsized thermos bottle and the mission as the "first real marriage of space engineering to fundamental scientific research in the manned space effort." It recognized the Spacelab as the first true scientific research station in orbit and a major advance over Skylab and probably over Salyut, the Russian Space Station then in orbit. Nevertheless, the scientific writers, particularly in Europe, questioned the vast investment in Spacelab for what appeared to be a small scientific return and an even smaller economic return to Europe. Although such writers were definitely in the minority, they represented an important school of thought within the European community, and one which would continue at the conclusion of the Spacelab 1 mission.

Nevertheless the die was cast, and Spacelab 1 was ready for launch (figs. 122 and 123). One final glitch occurred with the TDRSS when the Ku-band uplink capability was lost, but the decision was made to proceed with the mission using S-band uplink alone. This capability would have to be shared by the Orbiter operators and the Spacelab payload team. On November 26, press briefings were held at Cocoa Beach, Florida, and final review and approval by the NASA Administrator was given at the L−2 Review (2 days prior to launch). The cast of visitors for this mission was quite different from previous Shuttle missions because of the many representatives from European countries and their press. Every Spacelab program contractor had a contingent of enthusiastic participants on hand and the VIP reviewing stands were decked out with flags from the participating countries, including Japan, which had provided one of the experiments on board. The general public audience for this Shuttle launch was the smallest so far, probably because it was Thanksgiving weekend and Shuttle launches were starting to seem routine.

PRIMARY OBJECTIVE

It was repeatedly emphasized in press releases, briefings, and publications about this launch that the primary objective was to verify the Spacelab system and subsystem performance capability, to determine the Spacelab/Orbiter interface capability, and to measure the induced environment. These were the so-called verification flight test (VFT) objectives. Specifically, the VFT objectives were to verify the operational capability of the following Spacelab subsystems: environmental control, structures, command and data management, and electrical power distribution. The VFT was also to assess the habitability of the Spacelab module and evaluate the module and pallet environment to assure that the Spacelab materials were compatible with the space environment and that contamination limits were not exceeded on sensitive optical surfaces and other experiments. No amount of words, however, could overcome the fact that many millions of dollars had been spent to develop a complement of some 70 experiments in a joint ESA/NASA payload that would test the Spacelab system and its onboard crew far more than any of the planned verification flight tests.

SECONDARY OBJECTIVE

It was stated that the secondary objective of the mission was to obtain valuable scientific, applications, and technology data from a U.S./European multidisciplinary payload and to demonstrate to the user community the broad capability of Spacelab for scientific research. These were the objectives of the Spacelab payload, which had been assembled after many years of competitive selection, in-

Figure 122. Spacelab 1 installed in the Orbiter *Columbia* and connected to the crew compartment by the transfer tunnel.

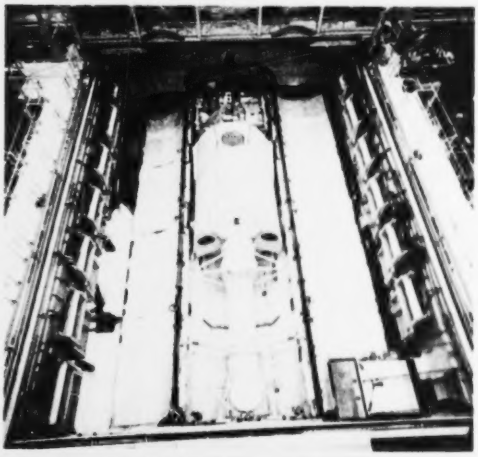
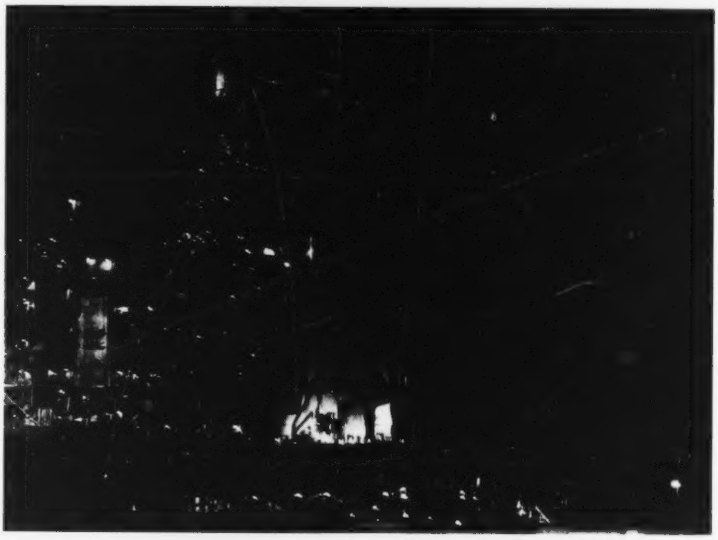


Figure 123. Shuttle mission STS-9 carrying Spacelab 1 awaits launch at KSC Launch Pad 39A after its second rollout from the Vertical Assembly Building.



strument development, resource allocation, training of the astronaut operators, planning and simulation of mission operations, analytical integration of hardware and software, and hands-on integration and checkout of the flight equipment. Chapter 5 traces the early steps taken by ESA and NASA to formulate this payload, sometimes described as a compilation of experiments with something for everyone. In fact, the chosen experiments fell into five space disciplines: astronomy and solar physics, space plasma physics, atmospheric physics and Earth observations, life sciences, and materials science. Experiment descriptions were first published in

NASA TM-78173 in May 1978, and a second edition was published in NASA TM-82448 in November 1981, which very nearly defined the final complement of experiments to be flown. The experiments included in the Spacelab 2 payload are listed in table 1.

Because of the large number of experimental facilities, investigations, and investigators and the way in which some facilities were utilized for numerous investigations (particularly the materials science double rack), a precise number count of the experiments is difficult. Thirteen of the investigations listed in table 1 were sponsored by NASA, the remainder by ESA. The materials science double rack facility with its 4 major components would be used by the crew to conduct 30 experiments for 44 investigators in the areas of crystal growth, fluid physics, and metallurgy. More than 120 co-investigators would support the principal investigators in the other investigations.

The complete story of the payload from its early definition through readiness for flight is beyond the scope of this book; however, the contributions of several key individuals need to be noted, at the risk of ignoring the contributions of many others. During the first several years, Bob Kennedy and then Bobby Noblitt provided NASA Headquarters leadership to the payload definition effort. By 1980, Mary Jo Smith had taken over as Payload Program Manager and performed in that capacity through the mission. At the time she took over, final confirmation of the experiments for flight was being given following the removal of some instruments in order to meet the weight limitations. The next year was one of schedule delays and development program stretch-outs because of slips in the Shuttle schedule and the continuing squeeze on the Spacelab payload budget as it struggled for funding against other ongoing science and applications programs. Despite these delays, the last piece of NASA experiment hardware had been delivered to KSC by April 1982. Assisting Mary Jo Smith in the mission preparations at NASA Headquarters was Dr. M. J. Wiskerchen, who served as NASA Program Scientist. The detailed planning and day-to-day work with the various investigators in the development of the instruments was done by the payload team at MSFC under O. C. Jean, Jim Downey, Bob Pace, Harry Craft, and Rick Chappell.

In the meantime, the European part of the payload, called by ESA the First Spacelab Payload (FSLP), had similar growing pains. Selected and sponsored at first by the science part of ESA Headquarters, specifically by a team led by Jacques Collet and Dr. Dai Shapland, the planning leadership soon was delegated to Drs. Jan Burger and Berndt Feuerbacher at ESTEC and Max Hauzeur, the first head of the Spacelab Payload Integration and Coordination in Europe (SPICE), reporting to Bignier's Spacelab Programme Directorate. In 1978, Derek Mullinger replaced Hauzeur as head of SPICE, and in 1981 when Feuerbacher left ESTEC for a new position at DFVLR, Dr. Karl Knott took over his role as ESA Project Scientist.

ESA subsequently selected ERNO as its Level IV integration contractor and assembled its pallet-mounted experiments in Europe on a bridging structure which spanned the front quarter of the Spacelab 1 pallet. A similar bridging framework called an orthogrid structure was utilized by NASA on the rear three-fourths of the

TABLE 1 *Spacelab 1 Investigations and Principal Investigators*

Investigation	*Principal Investigators*
Astronomy and Solar Physics	
Far-Ultraviolet Astronomy Using the FAUST Telescope	C. S. Bowyer University of California at Berkeley
Very Wide Field Camera	G. Courtes France
Spectroscopy in X-Ray Astronomy	R. Andresen ESTEC, the Netherlands
Active Cavity Radiometer	R. C. Wilson Jet Propulsion Laboratory
Solar Spectrum from 170 to 3200 Nanometers	G. Thuillier France
Measurement of the Solar Constant	D. Crommelynck Belgium
Space Plasma Physics	
Space Experiments with Particle Accelerators	T. Obayashi Japan
Atmospheric Emission Photometric Imaging	S. B. Mende Lockheed Palo Alto Research Laboratories
Phenomena Induced by Charged Particle Beams	C. Beghin France
Low-Energy Electron Flux and Its Reaction to Active Experimentation	K. Wilhelm West Germany
Direct Current Magnetic Field Vector Measurement	R. Schmidt Austria
Isotopic Stack-Measurement of Heavy Cosmic Ray Isotopes	R. Beaujean West Germany
Atmospheric Physics and Earth Observations	
Imaging Spectrometric Observatory	M. R. Torr Utah State University
Grille Spectrometer	M. Ackerman Belgium

Table 1 *Spacelab 1 Investigations and Principal Investigators (cont.)*

Investigation	*Principal Investigators*
Waves in the Oxygen-Hydrogen Emissive Layer	M. Herse France
Investigation on Atmospheric Hydrogen and Deuterium Through Measurement of Their Lyman-Alpha Emissions	J. L. Bertaux France
Metric Camera Experiment	M. Reynolds West Germany
Microwave Remote Sensing Experiment	G. Dieterle West Germany
Life Sciences	
Radiation Environment Mapping	E. V. Benton University of San Francisco
Advanced Biostack Experiment	H. Bucker West Germany
Microorganisms and Biomolecules in Hard Space Environment	G. Horneck West Germany
Effect of Weightlessness on Lymphocyte Proliferation	A. Cogoli Switzerland
Preliminary Characterization of Persisting Circadian Rhythms During Spaceflight	F. M. Sulzman State University of New York
Nutation of *Helianthus Annuus* in a Microgravity Environment	A. H. Brown University of Pennsylvania
Mass Discrimination During Weightlessness	H. Ross United Kingdom
Three-Dimensional Ballistocardiography in Weightlessness	A. Scano Italy
Personal Miniature Electrophysiological Tape Recorder	H. Green United Kingdom
Effects of Prolonged Weightlessness on the Humoral Immune Response of Humans	E. W. Voss, Jr. University of Illinois

Table 1 *Spacelab 1 Investigations and Principal Investigators (cont.)*

Investigation	*Principal Investigators*
The Influence of Space Flight on Erythrokinetics in Man	C. Leach Johnson Space Center
Measurement of Central Venous Pressure and Determination of Hormones in Blood Serum During Weightlessness	K. Kirsch West Germany
Vestibular Experiments	L. R. Young Massachusetts Institute of Technology
Vestibulo-Spinal Reflex Mechanisms	M. F. Reschke Johnson Space Center
Effects of Rectilinear Accelerations, Optical Kinetics, and Caloric Stimulations in Space	R. von Baumgarten West Germany
Materials Science	
Tribological Experiments in Zero Gravity	R. L. Gausse Marshall Space Flight Center
Crystal Growth from Solution Under Microgravity Conditions	K. Neilsen, G. Galster, I. Johannsen: Denmark; A. Authier, F. Lefaucheux, M. C. Robert: France
Crystal Growth of Mercury Iodide by Physical Vapor Transport	R. Cadoret France
Materials Science Double Rack Facility, Including Fluid Physics Module, Isothermal Heating Facility, Gradient Heating Facility, and Mirror Heating Facility	More than 30 different experiments for 44 investigators from 9 European countries
Crystal Growth of Proteins	W. Littke West Germany
Self-Diffusion and Inter-Diffusion in Liquid Metals	H. Weber, G. Frohberg, K. Krantz West Germany
Adhesion of Metals in an Ultra High Vacuum Facility	G. Ghersini, G. Grugni, F. Rossitto, P. Sona Italy

pallet to accommodate its external instruments. The ESA experiments which were to be carried within the module were mounted in their module racks and checked out in Europe before shipment to KSC. The most traumatic period during the payload preparation was ESA's difficult decision to remove the SLED experiment from the complement of Spacelab 1 experiments. The SLED was a very large and heavy experiment consisting of tracks and a seat which would have provided linear acceleration measurements on crew members in the module. However, there simply was not enough weight capacity available on this very crowded mission, and something had to give. Weight control had become a highly political issue on the Spacelab 1 mission, and the SLED would have to await the West German D-1 mission in October 1985.

The Spacelab Memorandum of Understanding had specified that the first mission would have a joint ESA/NASA payload. Unfortunately, it had not specified who was to manage the mission, although NASA was understood to be the operator of the total system. While the payload was in its formative stages, the NASA Mission Scientist, Dr. C. R. (Rick) Chappell of MSFC, was comfortable in sharing responsibilities with his ESA counterpart, Dr. Feuerbacher, in guiding the Investigators' Working Group and in making joint decisions with respect to the scientific objectives. As Harry Craft, the MSFC Mission Manager, got deeper into the activity soon to be called "analytical integration," it became obvious to him that one person had to be in charge and that it must be someone from NASA. Craft, a strong-minded and outspoken individual, accepted that mantle for his own and soon developed a reputation as a hard-driving manager who was going to make the Spacelab 1 payload into a logical complement of experiments and the Spacelab 1 mission into a scientific and technical triumph.

THE FLIGHT CREW

Chosen to command the flight crew for the Spacelab 1 mission was John W. Young, a veteran of five NASA space flights and one of the most experienced astronauts. He had flown two Gemini missions, made two trips to the Moon in Apollo, and had commanded the first Shuttle flight in April 1981. Assisting him as pilot would be Major Brewster H. Shaw, Jr., USAF, making his first space flight, although he was an experienced test pilot and flight instructor with 3500 flying hours in over 30 types of aircraft.

Drs. Robert A. R. Parker and Owen K. Garriott, who had been training for this mission since their selection in 1978, would be the Mission Specialists. Both had valuable Skylab program experience, Parker as Program Scientist on the ground, and Garriott as Science Astronaut on the Skylab 3 mission. Garriott, a ham radio buff, would add special interest to the mission with his planned attempts to communicate to the ground with a small hand-held radio unit. Garriott and Young were prepared to perform any contingency EVA if required.

The five Payload Specialists selected by ESA and NASA in 1978 as candidates for this mission had been narrowed to two. Claude Nicollier, one of the early ESA candidates, was in training to become a Mission Specialist and would probably fly on a later mission. ESA had selected Dr. Ulf Merbold as its Payload Specialist for this mission. Dr. Wubbo Ockels would serve as a backup Payload Specialist and would be located in the JSC Payload Operations Control Center during the mission to communicate with the onboard science crew. Dr. Byron K. Lichtenberg would be the NASA Payload Specialist, and Dr. Michael L. Lampton would be his backup, also playing a key support role in the POCC. Merbold was a graduate of the Max Planck Institute in Germany and a specialist in crystal lattice defects and low-temperature physics. Ockels, from the University of Groningen, the Netherlands, was a specialist in nuclear physics. Lichtenberg, an MIT graduate, specialized in biomedical engineering. Lampton, from the University of California at Berkeley, had research interests in space physics, X-ray and ultraviolet astronomy, and optical and electronics engineering. The Spacelab 1 crew is shown in figure 124.

This was certainly the most qualified, experienced, and trained flight crew ever selected for a space mission. The scientists had been intimately involved in the selection and preparation of the experiments and in the development and qualification of the basic Spacelab system. This was the most ambitious Shuttle mission ever undertaken and the crew was well prepared.

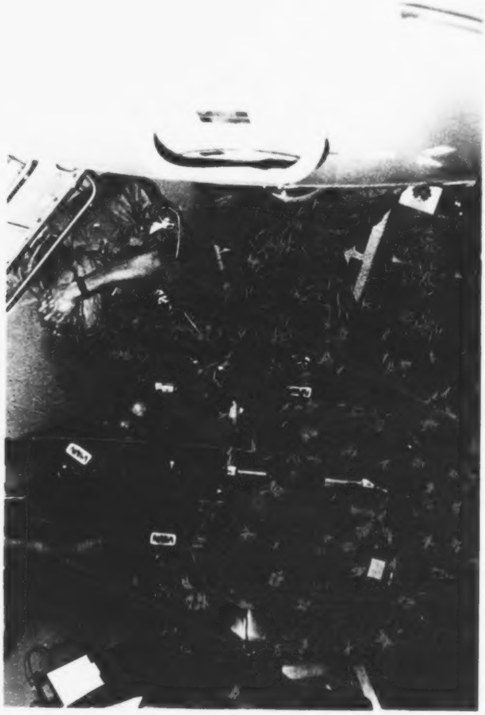


Figure 124. The six crew members of Spacelab 1 float effortlessly in the aft end cone of the Spacelab module during their historic mission. From the scientific airlock handle in the top foreground, clockwise, are Dr. Robert Parker, Commander John Young, Dr. Ulf Merbold, Dr. Owen Garriott, Pilot Brewster Shaw, and Dr. Byron Lichtenberg.

THE LAUNCH

Monday morning, November 28, 1983, finally arrived, and with it concern about the weather at the emergency landing site in Spain and the possible threat of thunderstorms in the Cape Canaveral area. The causeways were lined with the usual assortment of campers, cars, signs, flags, vendors, public address speakers, porta-johns, and sunbathers. The VIP stands were filled with enthusiastic supporters of the Spacelab program and a scattering of dignitaries and luminaries from the entertainment, political, and international arenas. A thriving business was under way in Spacelab and STS-9 mission mementos, first day covers, hats, and T-shirts. The huge countdown clock in front of the viewing area moved ever so slowly and paused at the planned holds for what seemed an eternity. Photographers maneuvered for the best spots, and the telephoto lenses looked like small howitzers aimed at the distant Shuttle launch complex. The public address announcer droned on with a running monologue of the countdown, but most people concentrated on looking around to see who they could recognize. Members of the Spacelab team not needed in the Launch Control Center or who had graduated from the program exchanged greetings and wished each other good luck.

Then, promptly at 11:00 a.m., it happened. The VIP stands grew silent for a moment, there was a small flash of light and larger puffs of smoke, and the Shuttle lifted majestically from the launch pad (fig. 125). Soon the reverberations from the Shuttle main engines and its boosters reached the viewing stands and overwhelmed the cheers from those looking on. The Shuttle quickly rolled around its axis and started to pitch over as it passed through the layers of clouds. Camera shutters clicked rapidly, old friends hugged each other with delight, and tears coursed the cheeks of many space-hardened veterans. There is nothing quite like those few moments after liftoff when everyone is of a single mind, trying to help push the launch vehicle into orbit.

Then, just as quickly, the launch was over. The low, staccato roar gradually diminished, the smoke and vapor trail began to break up, the flame became a point source in the distance and then was lost from sight. Now the words of the public address announcer could be heard again, calling off the mileposts in the sky as the Shuttle with its Spacelab payload was tracked, inexorably, toward its destiny. Could it really have happened so quickly? Yes, the cameras were being folded up, the stands were beginning to empty, the first busses were already leaving. Spacelab 1 was on its way.

THE MISSION

NASA Launch Manager Tom Utsman and Launch and Landing Director Al O'Hara described the liftoff as "very nominal" (normal to a layman). Both reusable rocket boosters were reported down at the planned target area in the Gulfstream,

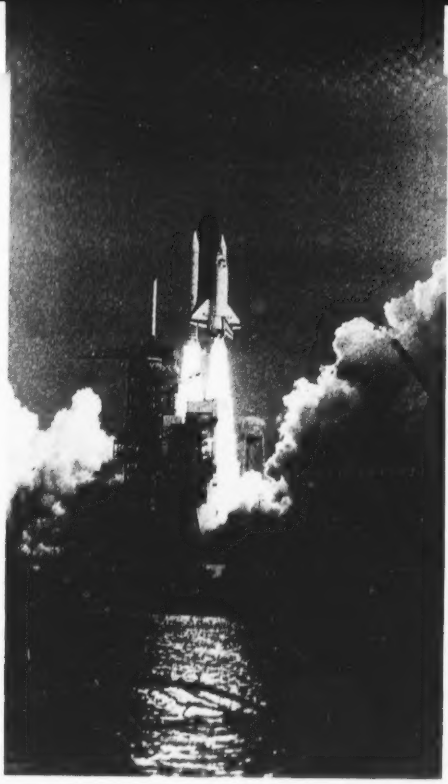


Figure 125. Spacelab's maiden flight begins at 11 a.m. EST on November 28, 1983, as STS-9 lifts from the launch pad at Kennedy Space Center.

125 miles east of Jacksonville, Florida. In a major deviation from previous Shuttle launches, *Columbia* immediately turned toward the northeast along the East Coast in order to achieve its planned orbital inclination of 57° at a 135-nautical-mile altitude.

The Shuttle, with its 33 584-pound Spacelab and pallet loaded with experiments (its heaviest payload to date), was now under control of the Mission Control Center at JSC and the Lead Flight Director, C. R. (Chuck) Lewis. Experiments were aleady under way during liftoff as Lichtenberg and Merbold wore biomedical headgear to monitor their eye motions during the launch phase. Once in orbit, Lichtenberg activated the lymphocyte experiment and within 3 hours of takeoff the crew was ready to open the airlock hatch and enter the Spacelab. For a few anxious moments, Garriott, Merbold, and Lichtenberg could be seen on network TV as they wrestled with the hatch, which appeared to be stuck. Then it opened, and the crew glided effortlessly into their new laboratory, shaking hands with each other and feeling right at home in the environment in which they had rehearsed for such a long time.

Shortly thereafter, the Red Team, consisting of Young, Parker, and Merbold, bedded down for their first rest period, the two teams already having adjusted on the ground to their planned work-rest cycles. The Blue Team of Shaw, Garriott, and Lichtenberg would take the first workshift and activate many of the onboard experiments. With the Shuttle oriented so that the cargo bay was facing the Earth and the Spacelab environmental control system performing flawlessly in providing the controlled environment for both the Spacelab and the Orbiter, the mission was off to a great start (fig. 126). Within the first day on orbit, 25 investigations were ini-

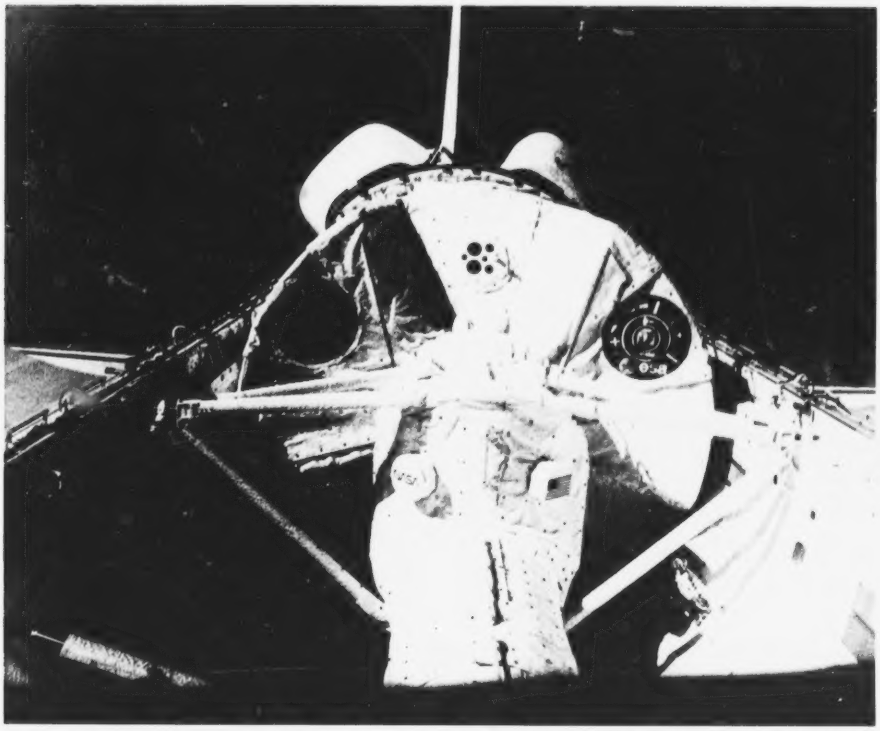


Figure 126. On-orbit view of the Spacelab transfer tunnel and module from windows in the *Columbia* crew compartment. Note ESA's Spacelab insignias on the module.

tiated, the only problem worth mentioning an intermittent fault with the remote acquisition unit in position 21 (RAU 21), causing many error reports to the onboard computer. The supporting ground crew promptly implemented workarounds to minimize the impact. Many of the early experiments were life sciences investigations, which were to obtain data before the adjustment to weightlessness was complete (fig. 127). As in previous manned flights, half the crew experienced varying degrees of motion sickness, which was not discussed in the open press for reasons of privacy. In fact, some of the experiments would be expected to drive the subjects to the brink of sickness, so a high percentage of such problems in this mission would not have seemed unusual. Parker received more than his share of attention when he insisted on falling asleep during one particular investigation. Meanwhile, Garriott was subjected to mild electric shocks in tests akin to a doctor's hammer for checking reflexes, and Shaw and Lichtenberg enjoyed playing with the mass discrimination experiment.

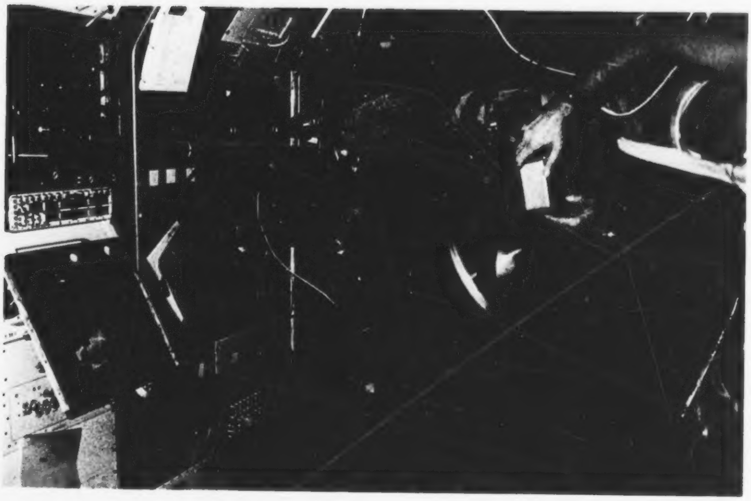


Figure 127. Mission Specialist Parker and Payload Specialist Merbold float in the Spacelab module while conducting biomedical tests.

On the second day, the cabin temperature was lowered according to mission plan and the scientific airlock was closed and repressurized. The Shuttle was reoriented with the cargo bay facing deep space for the cold test, and the scientific airlock operated successfully. RAU 21 continued to cause intermittent problems, but seemed to work better when its temperature was below a certain point. In the meantime, it was discovered that a faulty software input had resulted in an erroneous input to the Orbiter computer telling it the Greenwich mean time, and, as a result, experiments that needed to know the exact times of sunrises and sunsets were being operated at the wrong times. Within a day this problem had been tracked down and fixed, although Flight Director Lewis was not pleased with the time taken to find and correct the error. The press reported that the crew had been dropped, shocked, spun, blindfolded, injected, and brought to the brink of illness in 12-hour shifts to test human physiology. ESA Program Scientist Knott reported the measurements of the ratio of heavy hydrogen (deuterium) in the Earth's upper atmosphere as "a real discovery, a real first." He indicated it would help to improve the accuracy of predictive models of world weather and long-term climate changes. Thirty-three of the thirty-eight experiment facilities on board had by now been activated.

On the third day in orbit, the Shuttle continued to face deep space, and the structural temperatures were not as low as predicted. The airlock table was retracted and the hatch closed. In his "spare time," Garriott began talking to amateur radio operators with his ham rig, and consideration was being given to extending the mission for an extra day because the expendables were not being consumed as fast as had been anticipated. The "interactive" method of operation in which scientists in the Payload Operation Control Center could talk to the scientists on board Spacelab was, at times, working too well. At one point, Parker lost his patience. Asked to change a medical procedure in which he was engaged, to recharge a battery, restart a metals furnace, and check on an outside antenna, he responded: "If you guys would recognize that there are two people up here trying to get all your stuff done, I think you might be quiet until we got one or the other of them done." Later that day the crew fired the electron beam gun for the first time, sending a beam of electrons streaking toward the atmosphere in the skies above the northern Caribbean.

Having completed the Spacelab cold test with flying colors, the Orbiter crew reoriented the cargo bay toward the Earth on day 4. The Spacelab subsystems continued to operate satisfactorily and the TDRSS was performing flawlessly, although in a reduced mode because of earlier problems (loss of Ku-band uplink was the most recent loss). Limited to a single voice link to the ground for the most part, the Orbiter crew turned this over for the use of the scientists, with Young and Shaw making do with a minimum of operational chitchat. They were kept more than busy, however, with an exhausting number of Orbiter maneuvers to meet the needs of the various investigators (fig. 128).

Then it happened. The high-data-rate recorder, so essential for the accumulation of high-date-rate scientific information while the Orbiter was out of sight of the TDRSS, jammed. Parker was trained to replace the recording tape, but no provision had been made for onboard repair of this vital component, and there was no backup. If it could not be made operable, there would be a substantial loss of data to the mission. Crews on the ground and in space considered various alternative actions. Finally, after almost 6 hours of inoperation, Parker freed the capstan drive and the recorder began to operate again, as it did for the remainder of the mission. It was not discovered until after the mission that two of the three redundant drive belts had broken and probably jammed the capstan. After being loosened by hand, it operated successfully with the single remaining belt.

RAU 21 continued to act up and software patches were made to instruct the computer to ignore the error signals. The experiment computer operating system, essential software located in the Spacelab computer memory, suffered an unexplained dropout, but was quickly reloaded and then operated satisfactorily. Payload Specialist Merbold also had a chance to play repairman when he dislodged a sample that had become uncentered in the cooling chamber of a furnace, which would have prevented further experiments from being conducted in the furnace. Later Merbold was able to rewire a power supply in another furnace to circumvent a short circuit. The Huntsville Operations Support Center (HOSC) at MSFC played an important role in analyzing the problems and in making recommendations to JSC for corrective action. The HOSC, which had played a similar support role a decade earlier in the Skylab missions, was set up to enable government and contractor support teams to assess reports coming back on the Spacelab systems, its major subsystems, and individual components. Within minutes, technical teams could be assembled from around the world to focus the best intelligence available on a given problem and its solution.

By the fifth day, operations had settled into a routine, and the decision had been made to extend the mission to 10 days, weather permitting. The last of the astronomical investigations was now under way, and all astronomy measurements were expected to be completed by Sunday, December 4, when the Orbiter would be in continuous sunlight. In two dramatic achievements, the crew mixed metals to create a very light, strong alloy unobtainable on Earth and detected, for the first time, several chemicals such as hydrochloric acid in the air 50 miles above the Earth. Also for the first time, the crew produced a kind of convection motion (Marangoni) in liquid unobservable on the ground, to the delight of Italian scientist Luigi Napolitano, who described his field of microgravity in space as a fourth dimension for scientists. Dieter Andresen, an ESA investigator, was just as excited about the observations of strong sources of X-ray bursts among the stars. The Spacelab was providing a cornucopia of scientific results.

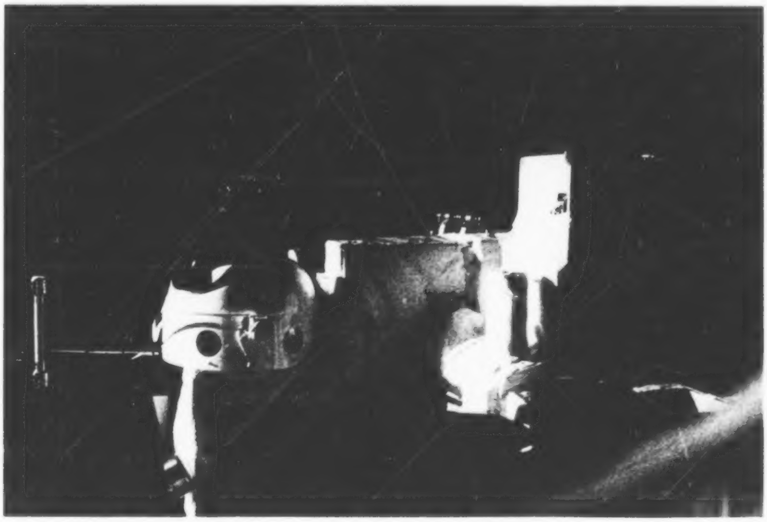


Figure 128. View from the aft viewport of the Spacelab module showing portions of eight experiments mounted on the pallet.

On day 6, electrical power in the module was reduced as far as possible to reduce the freon temperature on the pallet to see whether this would improve the performance of RAU 21 located on the pallet. Several operations with the wide-field camera were performed using the scientific airlock. Once again Parker had been successful in repairing a jammed piece of equipment. This time, using a sleeping bag in the crew compartment as an improvised darkroom, he worked on the aerial camera film magazine, which had jammed on a photographic pass over Europe, and was able to get it to operate again. Thirty-six of the thirty-eight experiment facilities had now gathered scientific data and the final two were turned on. Such a high percentage of experiment performance would have been considered unthinkable in the early planning days of Spacelab. Garriott was successful in another way on this day as he talked to a fellow ham enthusiast, King Hussein of Jordan, as the spacecraft streaked over the Red Sea and the Gulf of Aqaba.

The mission focused on international relations more than science on the seventh day, as a long-distance conference call and telecast was held among the orbiting Spacelab, President Ronald Reagan at the White House, and West German Chancellor Helmut Kohl in Athens at a European economic summit meeting. Later, Merbold, the first European to fly on an American space flight, treated his European visitors to a rhapsodic telecast of their homelands from on high and paid tribute to "*die Schoenheit der Erde*"—the beauty of the Earth. Young, Merbold, and Lichtenberg conducted a news conference with reporters in London, Brussels, The Hague, Bonn, Geneva, and Rome. Meanwhile, Shaw, Garriott, and Parker, who had been excluded from the presidential linkup, staged a good-natured "hear no evil, see no evil, speak no evil" scene from the Orbiter mid-deck during a television test before the actual telecast. Both Reagan and Kohl effusively commented on the significance of this Spacelab mission and its importance in terms of U.S./European cooperation. Although some Europeans may have felt the participation by West Germany was overemphasized in this telecast, West Germany rightfully deserved recognition as the prime mover and major financial supporter of the entire Spacelab effort. All of Europe could be proud of the achievement, but West Germany doubly so. As if to emphasize the importance of this political accomplishment, on the next day NASA Administrator Beggs met with President Reagan and received approval for a go-ahead on development of the long-awaited Space Station. Meanwhile, apart from the politics, the science achievements on Spacelab 1 were continuing. Focus was now moving toward observations of the Sun, and the film from the astronomical telescopes was put in storage for the trip home (fig. 129).

With the Orbiter cargo bay now pointed toward the Sun, the Spacelab was in a hot-case condition for day 8. A busy day was spent completing the access of data from the last of the 38 experiment facilities and in repeating experiments and observations to expand on the knowledge gained. A theory about human balance that had earned the Nobel prize for a scientist 70 years ago was disproved, or at least brought into serious question. The German contingent of industrial and academic scientists involved in the materials science experiments reported the first batch of extremely pure, carefully controlled crystals made in space. Meanwhile, the Spacelab O_2/N_2 subsystem was switched to the redundant branch to check its performance.

and RAU 21 stopped operating completely as the temperature increased. The environment within the module and transfer tunnel, however, remained very comfortable for the crew.

On day 9, the Orbiter returned to an Earth-pointing mode. Additional unplanned experiments could now be performed, as well as the completion of the planned scientific objectives. Then the airlock was secured and preparation for reentry begun. After 9 days of round-the-clock operation in the Spacelab module, there was considerable equipment stowage and tidying up to be done.

Day 10, the final day in orbit, was used for final Spacelab system checks and closing down the module. The pressurized volume provided by the module and transfer tunnel had been so tight that it had been unnecessary for the atmospheric makeup system to perform during the first 9 days of the mission. The pressure was purposely reduced, therefore, and replacement oxygen introduced with a monitoring of the resultant nitrogen flow. The system worked perfectly. Some additional solar observations were made during a solar-pointing hold to again observe the temperature profile and RAU 21 performance. A crash dump and reload of the ex-

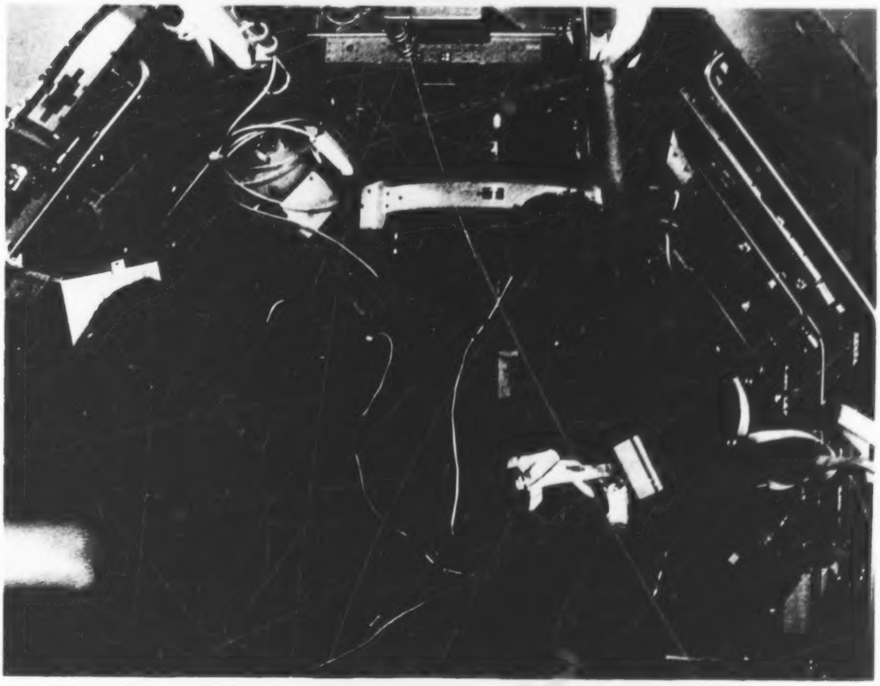


Figure 129. The four science specialists on Spacelab 1 congregate around the television monitor. Left to right: Parker, Lichtenberg, Garriott, and Merbold.

periment computer software was also conducted. At the end of the day, the crew returned to the Orbiter from the Spacelab module and closed the hatch. The Spacelab module had provided a secure living environment and demonstrated its usefulness as an efficient laboratory for space observations and investigations (fig. 130).

The plan was to land the Orbiter on the dry lakebed at California's Mojave Desert, home of Edwards Air Force Base and NASA's Dryden Flight Research Center, at 10:59 a.m. EST. *Columbia*, weighing more than 220 000 pounds, was heavier by 11 000 pounds than any previous Orbiter to be landed. Unfortunately, two of the five Orbiter computers and one of its three inertial measurements units failed to operate, and a delay of some 8 hours and five additional orbits transpired before *Columbia* finally touched down on the desert floor at 6:47 p.m. EST, December 8, 1983, after 10 days, 7 hours, and 47 minutes since liftoff at KSC. Instead of a northerly approach to the California coast as planned, the delay necessitated a southerly approach from the Aleutian Islands and down California's Central Valley, but ended in a beautiful landing for *Columbia* and its very tired crew (fig. 131). Although the crew did not realize it at the time, leaking hydrazine fuel from two of *Columbia's* auxiliary power units had started a small fire that led to an explosion 15 minutes after landing. Fortunately, no serious damage was done and the crew was in no imminent danger. The extra time in orbit and the crew's exhaustion resulted in modifications of the plans for extensive medical examinations of the science crew on the ground. However, the four crew scientists were kept in isolation for a week of careful monitoring of their readaptation to gravity after landing. Nevertheless, the mission had to be considered a resounding success, or as John Thomas, NASA's Spacelab Program Manager stated, "an unprecedented accomplishment in manned space flight." Mission Manager Harry Craft reported that the flight had yielded 20 million pictures and 2 trillion bits of data, and he said, "We have completed a major international scientific venture, and demonstrated without any doubt that Spacelab is a fantastic vehicle for performing science in space."

MISSION AFTERMATH

Columbia's tires had not yet cooled from landing before discussions resumed about the political significance of the Spacelab 1 mission and its implications for further cooperative efforts in space between the U.S. and Europe. The technical, scientific, and managerial achievements of the Spacelab program and the Spacelab 1 mission were no longer in question: the remaining controversy was about the mission's

Figure 130. Payload Specialist Lichtenberg conducts an investigation using the materials science double rack.

MAXIMUM
CAPACITY
PERSON
Columb

Figure 131. The STS-9/Spacelab 1 crew descends from the Orbiter *Columbia* after its record 10-day mission ended with a landing at Edwards Air Force Base, California.

portent for the future. With NASA expecting momentarily to announce support from President Reagan and the U.S. Congress to start development of a permanently manned Space Station, what would be Europe's role in such an undertaking? Hermann Strub of the West German Federal Ministry of Research and Technology was quoted as saying: "This time it will be different. Spacelab has given our industry the experience of managing a major project for manned space operations. In 1973, the United States did not think Europe could do it, indeed no one believed in European technology in space. After Spacelab, NASA's technical people tell me they have the highest regard for what we can do; this time it should be a real partnership." Herbert Curien of France's Centre Nationale d'Études Spatiales was quoted in a similar fashion as saying: "One of our conditions is that a European contribution should be an integral part of the Space Station, not something which is merely an addition to it." Even Jacques Collet, a long-time friend of the Spacelab team and now head of the long-term program planning office in ESA's Directorate of Space Transportation Systems, expressed concern over access: "The Space Station is a project with an unlimited timespan; we have to be assured that we can use it when we want."

Payload Specialist Ulf Merbold, now a hero to European, particularly German, space buffs, picked up the theme. As the crew of the Spacelab 1 mission made media appearances and goodwill tours, Merbold was increasingly sought out for his provocative views of the Spacelab as a cooperative space venture. In particular, he reflected on the poor deal which Europe received: half a space mission for a billion-dollar Spacelab. Cooler heads in Europe, party to the entire history of the program, realized that the situation could not be reduced to such a simplified equation. The managerial expertise gained by Europe, the U.S. purchase of additional Spacelab hardware, the stimulation of advancements in the state of the art of European space technology, and the expertise in conducting the joint operations of this very ambitious mission were benefits to Europe which could not be measured in deutschmarks or lira. On at least one point, however, all were agreed. Because of Spacelab, Europe was now in a different negotiating position with respect to future cooperation with the U.S. in manned space ventures.

On January 19, 1984, Spacelab Program Manager Thomas presented a preliminary report on Spacelab 1 mission results to Administrator Beggs, followed by a preliminary science report from Mission Scientist Chappell. From the Spacelab viewpoint, it is hard to visualize a more successful mission report. All objectives were successfully achieved, including 17 detailed test objectives, 81 functional objectives, and 361 verification measurements. The systems performance was excellent, the environment near or better than predicted, the habitability provisions were excellent, the crew demonstrated its effectiveness and resourcefulness, and the five recorded anomalies did not significantly affect the mission. In only three areas did the team recommend consideration of improvements to the Spacelab subsystems: data system redundancy (multiplexer and recorder), intercom (flexibility and multiple loop operation), and computer/display response (too slow).

The preliminary science report from Rick Chappell was almost as good: in materials science 80 percent of the samples were processed or experiments run, the highlights being the observation of large liquid bridge oscillations, the first floating zone silicon crystal grown in space, the Marangoni convection, and the successful growth of protein and organic crystals. Some 65 percent of the atmospheric physics and Earth observations objectives were accomplished, highlighted by the first comprehensive scan of dayglow from the upper atmosphere, the first observations of CO_2 and H_2O in the thermosphere and methane in the mesosphere, and the discovery of deuterium in the upper atmosphere. In astronomy and solar physics, more than 90 percent of the planned objectives and observations were achieved, including the high-resolution measurement of X-ray lines from stellar sources, an apparent background in the far-ultraviolet range which may limit observations at Spacelab altitudes (at least in the particular orbit and lighting conditions of Spacelab 1), and measurement of the solar constant and solar spectrum. In space plasma physics, some 88 percent of the objectives were attained, including studies of vehicle neutralization by magneto plasma dynamics and neutral gas plume, observation of beam-plasma discharge phenomena, generation of energetic return electrons during beam firings, successful joint experiments using multiple instrumentation, and imaging of airglow layers in the upper atmosphere. In the life sciences, more than 90 percent of the planned operations, studies, data, runs, samples, and objectives were accomplished, with highlights being new evidence on the mechanism of caloric nystagmus, a possible higher threshold for sensing linear acceleration by the otolith, some increased dependence on visual cues for orientation, low central venous pressure, strong effect of microgravity on lymphocyte proliferation, and persisting circadian rhythm in neurospora. From the standpoint of its significance for manned space science, Chappell concluded that Spacelab 1 proved the value of merging manned space flight and space science, demonstrated NASA's commitment to involve the scientist strongly in manned science missions from design through operation, showed the effectiveness of scientist-to-spacecraft interaction, proved the operational approach of 24-hour operation and scientists flying as Payload Specialists, showed that Spacelab is a valuable capability for space science, and served as a harbinger of a strong future for Space Station and Space Platform activities.

Only one gesture remained to confirm the success of the Spacelab 1 mission. On February 29, 1984, Samuel Keller, NASA Deputy Associate Administrator for Space Science and Applications, signed the Assessment of the Spacelab 1 Mission, which stated, "The Spacelab 1 mission is judged a success. Demonstration of Spacelab as an orbiting laboratory is an unqualified success." On March 1, General Abrahamson signed the same statement as the NASA Associate Administrator for Space Flight. It was now official.

Within a few months, results of the scientific accomplishments started to appear in scientific publications, although full analysis of the data would require months, even years of study. The American Association for the Advancement of Science devoted a major portion of its July 13, 1984 issue of *Science* to the Spacelab 1 results. The British publication *New Scientist* of August 23, 1984 presented a similar summary. The British editor took the opportunity to needle the Spacelab program for the purported poor quality of its science, the question of the need for man in space laboratories, the poor planning of ESA in expending all its resources on experiment development and operational support, leaving insufficient funds for European data analysis, and the now-familiar expression of hope that in the Space Station program the European taxpayer will not again be taken for a ride. The editorial by Philip Adelson in *Science* was a much more positive assessment. His final paragraph merits full quotation: "Those who go into a laboratory for the first time to conduct an experiment under new conditions are lucky when they have any kind of result to show for their efforts. The patient and careful planning for Spacelab 1 paid off in the many results reported in this issue. The achievements thus far are a good omen for further successes as the lessons learned to date are used in planning for later Spacelab missions."

SPACELAB 3 MISSION

The September 1980 payload flight assignment schedule issued by Chet Lee's Space Transportation Systems Operations Office had forecast a logical phasing of Spacelab missions for the next several years, including Spacelab 1 on the 10th Shuttle launch in June 1983, Spacelab 2 on the 14th launch in November 1983, Spacelab 3 on the 20th launch in April 1984, Spacelab 4 on the 22nd launch in May 1984, and the dedicated German mission Spacelab D-1 on the 25th launch in August 1984. Beyond that time, dedicated Spacelab missions were expected to fly about twice each year and occasional isolated pallets of opportunity would be flown in-between. Following the problems with the first TDRSS launch, changes in DOD mission plans, redesign and subsequent delay of the Spacelab Instrument Pointing System required for the Spacelab 2 mission, and other payload problems, coupled with periodic problems with the Shuttle itself, the payload schedule changed drastically. By the time the Spacelab 1 mission was flown on the 9th Shuttle flight, Spacelab 3 was scheduled to be flown as the next Spacelab mission in November 1984, with Spacelab 2 delayed until March 1985.

Preparations for the Spacelab 3 mission had already commenced by March 1983 with the Payload Ground Operations Review and in October 1983 with the start of Level IV integration of payload elements (fig. 132). The next year witnessed the inexorable approach of launch time, but a slip of the planned launch date, due to several factors, from November 1984 to April 1985. The Cargo Integration Review was completed by October 1984, the Integrated Hardware/Software Review by February 1984, and the Flight Operations Review and the Cargo Readiness Review by October 1984. With the completion of the Flight Readiness Review in early April 1985, the Orbiter *Challenger* and its Spacelab 3 payload were ready for an end-of-month launch.

THE PAYLOAD

Spacelab 3 was planned to be the prototype of a NASA-dedicated Spacelab mission. Rather than containing experiments covering a broad range of disciplines as in Spacelab 1, the Spacelab 3 payload would focus on microgravity for most of its investigations, with the Orbiter in a gravity gradient attitude, its tail pointed toward the Earth, to provide the best stability possible. As few as 50 firings per hour of the vernier thrusters would minimize the impact on the Orbiter and its payload to less than one-thousandth of a g-load. The Spacelab 3 experiments are shown in table 2.

In addition to the Principal Investigators named in table 2, some 40 Co-investigators were involved in the experiments. Three members of the flight crew were intimately involved in three of the experiments: Mission Specialist Don Lind as a Co-investigator on the auroral imaging experiment, Payload Specialist Taylor Wang as Principal Investigator on the drop dynamics module, and Lodewijk van der Berg as Co-investigator on the vapor crystal growth system. The French mercury iodide experiment was the first reimbursable effort of the Spacelab program: NASA was paid to fly this experiment by the French space agency, CNES. The French experiment was a repeat of an investigation conducted on the Spacelab 1 mission, as was the very wide field camera which would be mounted in the scientific airlock. Equipment for auroral viewing and for urine monitoring was mounted in the Orbiter crew compartment. The atmospheric spectroscopy and Indian cosmic ray experiments were mounted on an experiment support structure (the MPESS) replacing the pallet used in Spacelab 1 for the externally mounted instruments. The remaining experiments were located in the Spacelab module, which had been stripped of its

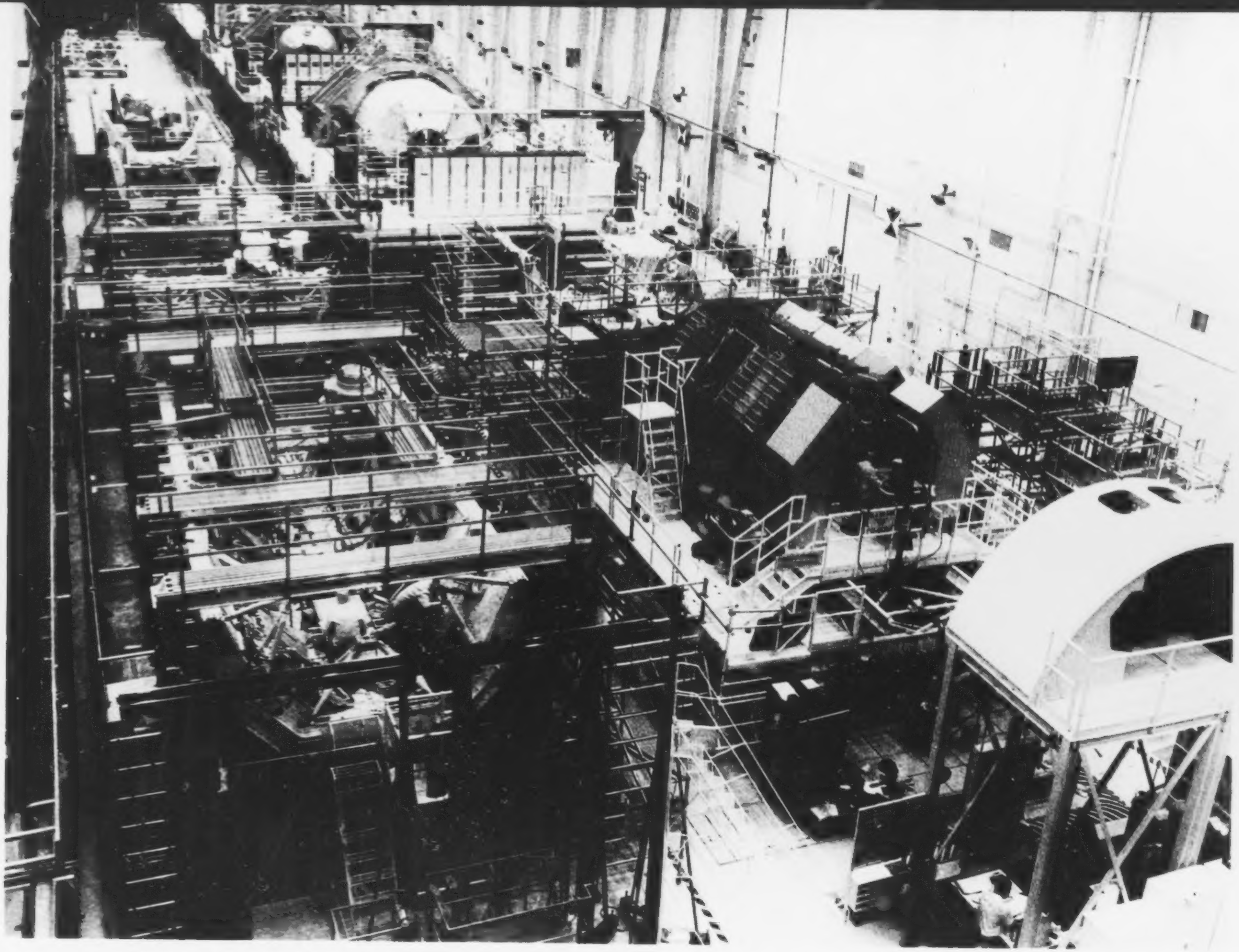


Figure 132. Peak of Spacelab integration and checkout activity at the Operations and Checkout Building at Kennedy Space Center, April 1984. The Spacelab 2 pallets are mounted in the test stand in the left foreground; immediately behind them is the Spacelab 3 experiment support structure. The Spacelab 3 experiment racks are shown in the right foreground test stand. The engineering model is shown at the top of the photo; the Spacelab 3 module is shown immediately before it.

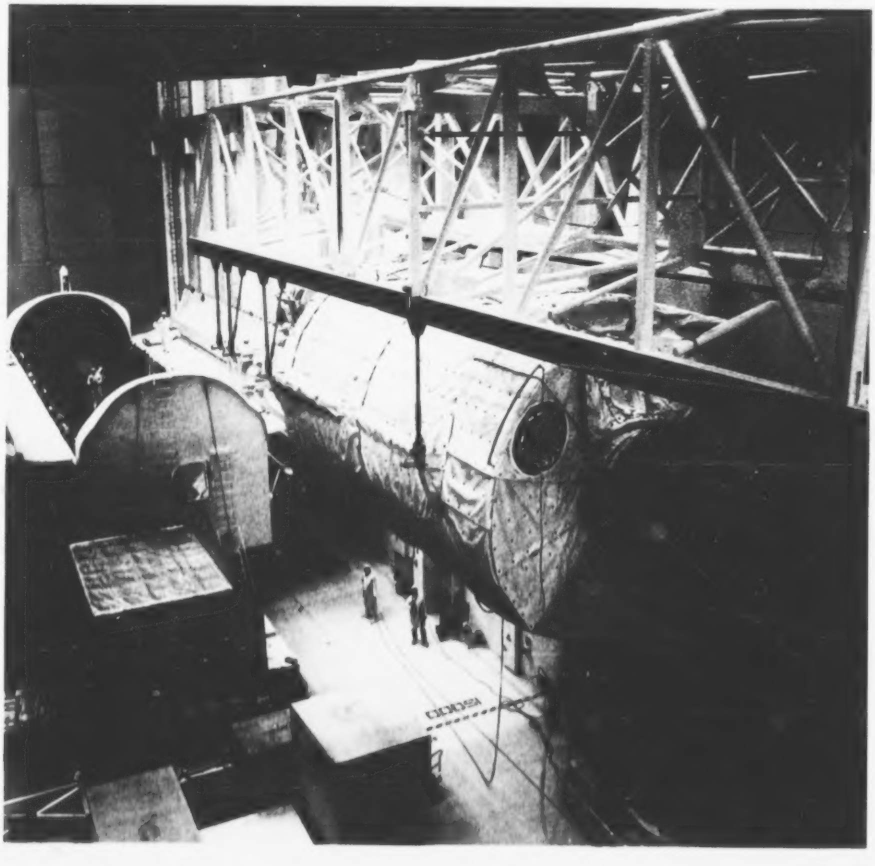
Table 2 *Spacelab 3 Investigations and Principal Investigators*

Investigation	*Principal Investigator*
Materials Science	
Solution Growth of Crystals in Zero-Gravity	Ravindra B. Lal Alabama A&M University
Mercuric Iodide Growth: Vapor Crystal Growth System	Wayne F. Schnepple EG&G Energy Measurements, Inc.
Mercury Iodide Crystal Growth	Robert Cadoret France
Life Sciences	
Ames Research Center Life Sciences Payload	Paul C. Callahan, John W. Tremor Ames Research Center
Autogenic Feedback Training	Pat Cowings Ames Research Center
Urine Monitoring Investigation	Howard Schneider Johnson Space Center
Fluid Mechanics	
Dynamics of Rotating and Oscillating Free Drops	Taylor G. Wang Jet Propulsion Laboratory
Geophysical Fluid Flow Cell Experiment	John Hart University of Colorado
Atmospheric and Astronomical Observations	
Atmospheric Trace Molecules Spectroscopy	C. B. Farmer Jet Propulsion Laboratory
Studies of the Ionization of Solar and Galactic Cosmic Ray Heavy Nuclei	Sukumar Biswas India
Auroral Imaging Experiment	Thomas J. Hallinan University of Alaska
Very Wide Field Camera	George Courtes France

Spacelab 1 payload and reconfigured for this mission (fig. 133). The Ames Research Center life sciences payload consisted of four important elements: a research animal holding facility for rodents, a research animal holding facility for primates, a biotelemetry system for measuring the physiological functions of the animals, and a dynamic environment measurement system for monitoring noise, vibration, and acceleration in the vicinity of the animal holding facility during ascent and reentry. These were essential elements for the development of an animal research facility in space, and the mission would be an important test of the design and operation of this facility, which had been under development at Ames for several years.

Scientific planning for Spacelab 3 had also been under way for several years. The payload was sponsored by the NASA Office of Space Sciences and Applica-

Figure 133. Assembled Spacelab 3 module and experiment support structure being moved to the payload canister for transfer to the Orbiter Processing Facility.



tions, and mission management was assigned to Marshall Space Flight Center. In early 1980, Sterling R. Smith transferred from the Spacelab Program Office to the Spacelab Mission Integration Division to serve as Headquarters Program Manager for the Spacelab 3 payload. After several years in this position, he turned the leadership over to Robert A. Schmitz, who continued in this role for the Shuttle Payload Engineering Division through the completion of the mission. Dr. John S. Theon of the Earth Science and Applications Division provided Headquarters support as Program Scientist. Meanwhile, at Marshall, Joseph W. Cremin filled the key position of Mission Manager and Dr. George H. Fichtl the role of Mission Scientist.

THE FLIGHT CREW

This time a crew of seven would be on board the Spacelab 3 mission, which now was designated Shuttle mission 51-B. Col. Robert F. Overmyer, who had been Pilot on the fifth Shuttle mission, would be in command, and the Pilot would be Col. Frederick B. Gregory, making his first space flight. The three Mission Specialists were Dr. William E. Thornton, a medical doctor and Mission Specialist on the eighth Shuttle flight; Dr. Norman E. Thagard, also a medical doctor and Mission Specialist on the seventh flight; and Dr. Donald L. Lind, a space physicist making his first flight after a 19-year wait. The Payload Specialists, both making their first flights, would be Dr. Lodewijk van der Berg, an employee of EG&G Energy Measurements and an authority on the vapor growth technique for producing mercuric iodide crystals, and Dr. Taylor Wang of the Jet Propulsion Laboratory, a physicist and inventor of the acoustic levitation and manipulation chamber in the drop dynamics module. Dr. Mary Helen Johnston, a metallurgical engineer from MSFC, and Dr. Eugene H. Trinh from JPL, a Co-investigator with Dr. Wang on the drop dynamics module, would be backup Payload Specialists. As in the previous mission, the crew would be divided into two teams for 24-hour operations, with the Silver Team consisting of Overmyer, Lind, Thornton, and Wang; the Gold Team, Gregory, Thagard, and van der Berg. The Spacelab 3 crew is shown in figure 134.

THE MISSION

The final step before launch was the placement of 12 squirrel monkeys and 24 rats in the animal holding facility in the Spacelab module, using the vertical assembly kit for the first time in an operational setting. The kit consisted of a crane mounted in the Orbiter mid-deck and pulleys and ropes for lowering equipment and technicians on a bosun's chair down through the transfer tunnel to the module. It had been under development for 2 years and had been tested in an elaborate Spacelab mockup using the Apollo spacecraft altitude chamber in the KSC Operations and Checkout Building. McDonnell Douglas Technical Services Company in-

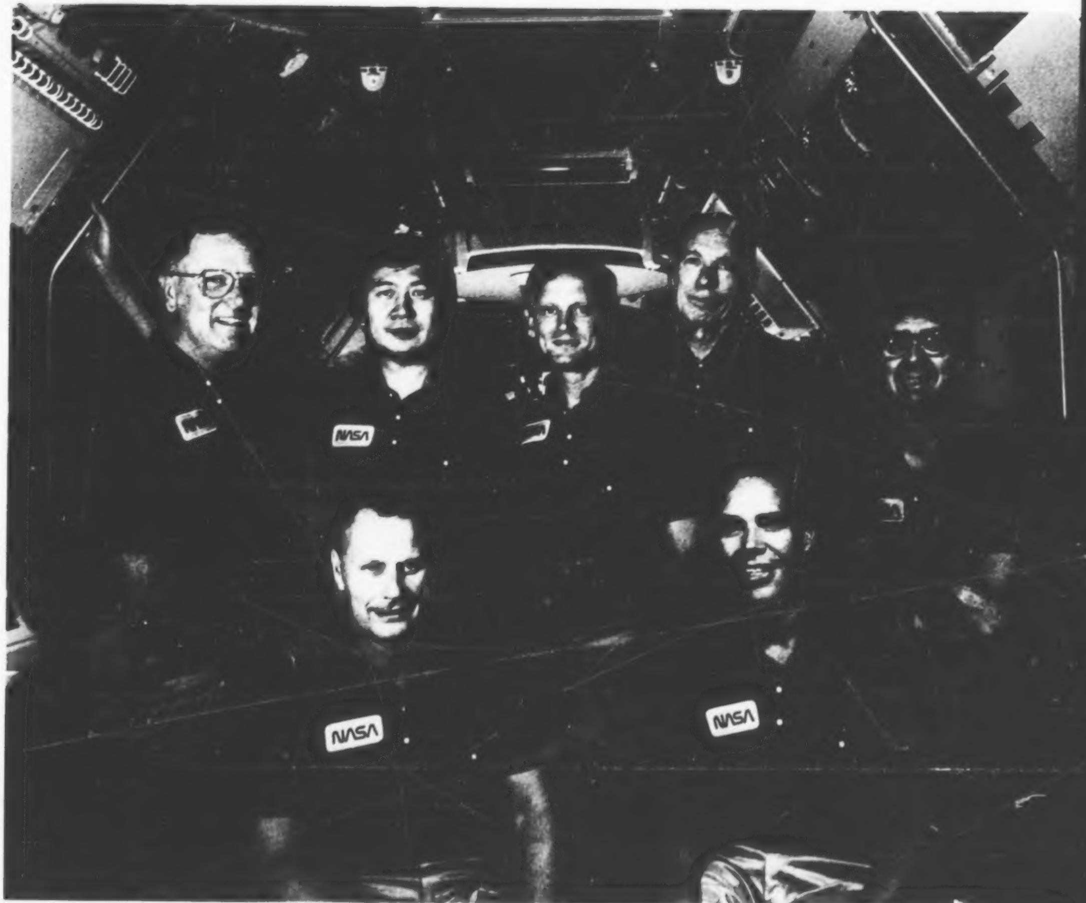


Figure 134. The crew of Shuttle mission STS 51-B (Spacelab 3). At the bottom, left to right, are Commander Robert Overmyer and Pilot Frederick Gregory. Behind them, left to right, are Dr. Donald Lind, Dr. Taylor Wang, Dr. Norman Thagard, Dr. William Thornton, and Dr. Lodewijk van der Berg.

stalled the vertical access kit and assisted Boeing Services International technicians who had the final responsibility for placement of the animals. At last, all was ready for launch.

In the quickest turnaround between Shuttle launches (*Discovery* had landed April 19 after a 7-day mission), *Challenger* roared off from its launch pad at 12:02 p.m. EDT, April 29, 1985. Once into its 57° inclined orbit at 190 nautical miles altitude, the Shuttle and its crew of seven quickly got to work. The launch of a small piggyback satellite to calibrate air traffic control ground radars went smoothly, but a second Navy satellite refused to budge from its cradle in a "getaway special" canister. A problem with the astronauts' fresh water supply was quickly overcome and the Spacelab module was soon opened for business, with the monkeys and rats apparently in good shape (fig. 135). The next day, however, word was reaching the ground that the crew was spending a considerable amount of its time cleaning up food and fecal materials which had escaped from both animal holding facilities. This was not a good omen for the animal research objectives; in particular, the food bars seemed to be too dry and crumbly. A more serious problem was encountered when the scientific airlock could not be opened the second time it was used, thus preventing deployment of the very wide field camera to obtain data in the night skies which would supplement those obtained during Spacelab 1. Wang and his cohort on the ground, Trinh, were also having problems with their drop dynamics module and were trying to figure out how to get it working. Despite these problems, 9 of the 15 experiments were up and running even better than had been hoped. Spectacular television pictures of the Northern and Southern Lights were beamed down as the Orbiter flew near the North and South Poles.

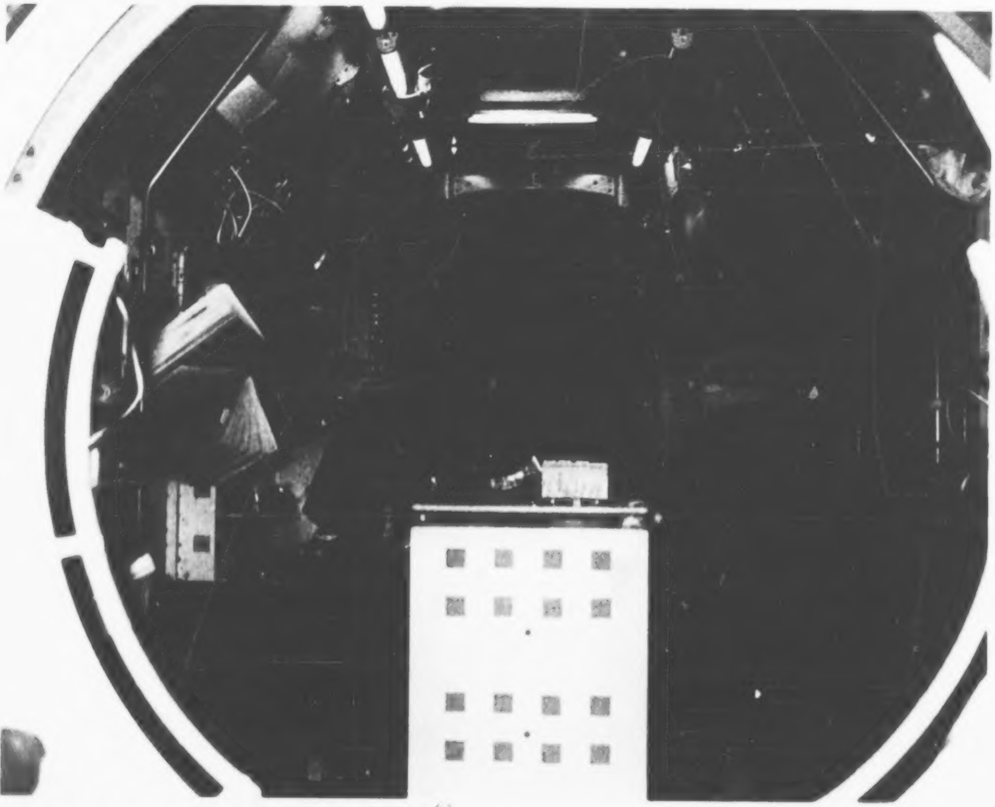
By the third day, 11 of the 15 experiments were operating successfully, and one of the monkeys was showing signs of space sickness, though the other appeared to have adjusted to weightlessness and cavorted freely in his cage. Lead Flight Director Gary Coen reported from JSC that it was doubtful the 7-day mission would be extended to give the crew a chance to work on the camera and the other balky experiments. *Challenger* did not have the capability for an extra set of tanks to provide the extra hydrogen and oxygen for its fuel cells that had been provided by its sister Orbiter, *Columbia*, in the Spacelab 1 mission.

Figure 135. Mission Specialist William Thornton checks one of the primates on the Spacelab 3 mission.

On the fourth day, waste products appeared to be getting loose from the animal cages again, forcing the crew members to rearrange their tight schedules and scramble about in full surgical gear to clean up after their passengers. The only reason given from the ground was that the animals were so spirited in their weightless environment, they were inducing turbulence in the cage that was stronger than the air flow designed into the cages to control the waste products. This explanation was not very comforting to the crew. Another piece of bad news was the failure of the laser spectrometer, although it had worked flawlessly for the first days of the mission, measuring as many as 40 different chemical molecules that cluster in the upper atmosphere. The most rewarding moment on this day came when Wang finally got his drop dynamics module to work (fig. 136).

By day, the crew was ecstatic over its success in making emergency repairs. Wang had found and bypassed a short circuit in one of three electronic boxes in the drop dynamics module, and Lind restored service to the cosmic ray counter by

Figure 136. Payload Specialist Taylor Wang works on the drop dynamics module at left, while other scientists conduct another experiment.



switching a connector cable from a failed experiment. Meanwhile, Thornton had rejuvenated the sick monkey with some hand-feeding, and it was eating everything in sight. The crew was not happy, however, with the continued spillage of waste from the animal cages whenever the food or waste trays were being changed. Gregory, meanwhile, joined the fix-it team by using cardboard strips and some wire to repair a damaged movie camera.

On the sixth day, the crew reported success on 12 of the 15 experiments. Both monkeys seemed fine, and the rats were reported to have loved every minute of the flight. Wang's experiment was working so well he spent hours showing it off to his colleagues on the ground, using sound waves to move drops of liquids around in a containerless environment.

The final day in space was spent shutting down the experiments in preparation for Monday's landing and in maneuvering the Orbiter's fuel tanks into the shade prior to the reentry firing. These were the first large thruster firings in 6 days and a welcome relief to the Commander and Pilot. The crew and Mission Manager Cremin awarded the Spacelab an "A" for its performance and began closing it up for the return to Earth. Although there had been a failure of the experiment computer, the system had been switched to the backup computer which performed flawlessly for the rest of the mission. Meanwhile, the two 75-member teams that had provided science support from the Payload Operations Control Center, and the TDRSS, which had provided yeoman support throughout the mission, prepared for a well-deserved rest. The Mission Control Center, its customer support room (fig. 137), and the backup crew at the Huntsville Operations Support Center would not rest easily, however, until the Orbiter and its Spacelab payload were safely on the ground.

This time the Orbiter made its approach over Long Beach and Los Angeles, its two sonic booms triggering burglar alarms and calls to the police. *Challenger* touched down on Edwards Lakebed Runway 17 just after noon, EDT, May 6, 1985, at a weight of 213 000 pounds, the second heaviest landing of the Shuttle program. Within 3 hours of landing, ground crews began removing the monkeys and rats for transport to KSC and further analysis. Spacelab 3 had apparently been another unqualified success for the Spacelab program.

MISSION AFTERMATH

Some time to think about the mission did nothing to diminish the euphoria over its accomplishments. Principal Investigator Dr. Barney Farmer exulted over the success of his laser spectrometer in measuring from orbit the ozone layer that protects the Earth from the Sun's searing ultraviolet light, stating "We made 19 observations of the ozone layer, and I would say we got more information out of those 19 than scientists had in all the previous balloon flights in the last 10 years." The 18 auroras seen and photographed by *Challenger*'s crew were reported as "spectacular and all different."

Wang's containerless processing had achieved 85-90 percent of its objectives despite the late start. The Indian experiment was salvaged despite a failure in its remote acquisition unit by the timely switching of wires from the atmospheric sensor experiment (which itself had failed from an internal problem) only after the latter had returned important atmospheric data. A leak in the experiment cell for growing an infrared crystal from fluid was overcome to provide the homogeneous structure desired. The crystal grown from vapor was 20 times the size of its initial seed and a backup was obtained. Although the animal holding facilities had given considerable trouble during the mission, postflight analysis of the air filters revealed a very small quantity of animal fecal material, contrary to what had been expected from the crew reports. It was obvious, however, that the food bars and cages would require further refinements before another Spacelab life sciences mission. Other mission highlights were that the geophysical fluid cell exceeded its 84 hours of atmospheric dynamics tests by about 20 hours, and important data were obtained on biofeedback techniques for controlling space motion sickness. Perhaps the most discouraging report from the mission was the lack of data from the wide-field camera caused by the crew's inability to open the scientific airlock. Since the airlock had operated successfully a few hours earlier as well as on the previous flight and since the postflight inspection revealed no damage (other than a bent handle) or cause for jamming, there is strong possibility that an incorrect procedure was used.

Taken in context, Spacelab 3 had to be given high marks as an operational mission, and the Spacelab had demonstrated again that it provided a useful laboratory for manned scientific missions in low Earth orbit. The next test would determine whether the pallet-only mode would be as successful.

SPACELAB 2 MISSION

Much of the background of this mission has been discussed earlier. Like Spacelab 1, Spacelab 2 would be a verification test of the Spacelab system. Only this time, there would be no laboratory module; instead, the crew would be confined to the Orbiter crew compartment. The igloo (shown in fig. 138), mounted on the forward pallet, would provide Spacelab subsystem support to the instruments located on this pallet, to a two-pallet train behind it, also loaded with instruments, and to the cosmic ray experiment with its special structure in the rear of the Orbiter cargo bay. Since it was a test flight and considered part of the Spacelab development effort, ESA would provide sustaining engineering support at its own expense; however, the payload was not a joint ESA/NASA effort.

The planned launch date of March 1985 again proved to be overly optimistic, as the Spacelab 2 mission gradually worked through its list of critical milestones. The Ground Operations Review of the payload was held in March 1983, and Level IV integration of experiments began in October 1984, in parallel with processing of the Spacelab 3 payload. Everybody was concerned about the Instrument Pointing System and its readiness to support Spacelab 2, which was critical to the mission's

Figure 137. Customer Support Room for the Spacelab 3 mission at the Mission Control Center at Johnson Space Center.

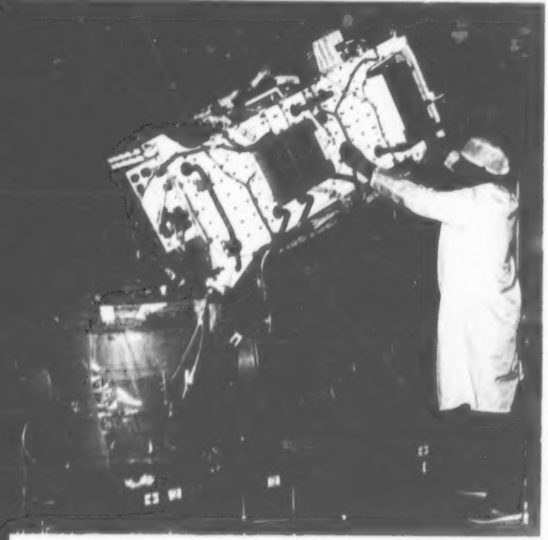
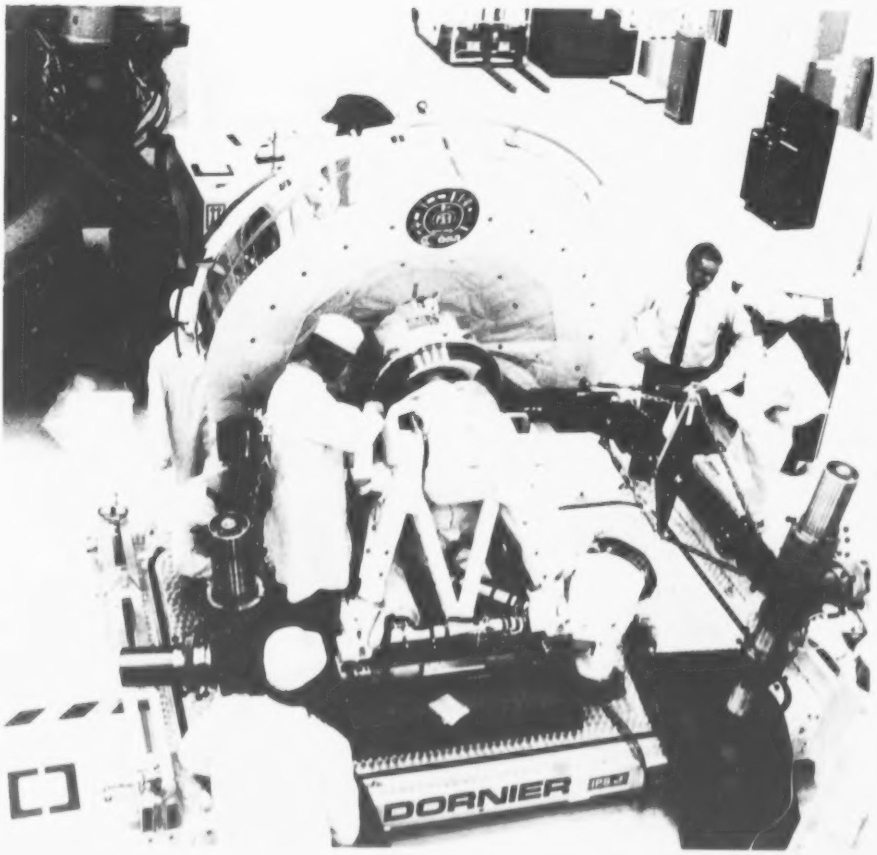


Figure 138. Spacelab igloo being readied in the Operations and Checkout Building at Kennedy Space Center for the Spacelab 2 mission.

success. Although the IPS had finally been delivered to KSC in November 1984 (fig. 139), it had been accepted with considerable open work, particularly in the area of software, and a special Design Certification Review had to be completed in early 1985 before final flight readiness could be assured. In addition, as with the Spacelab 1 configuration, tests were required in the cargo integration test equipment (CITE) stand before the pallet configuration would be installed in the cargo bay of the Orbiter. Finally all the reviews were completed: the Cargo Integration Review and Integrated Hardware/Software Review in July 1984, the Flight Operations Review and the Cargo Readiness Review in May 1985, and the Flight Readiness Review in early July, in time for a planned launch on July 12.

Figure 139. The Instrument Pointing System arrives at Kennedy Space Center from Dornier System, November 1984.



THE PAYLOAD

Although not as crowded as Spacelab 1 with its 38 experiment facilities, the Spacelab 2 payload contained 13 investigations in 7 scientific disciplines to demonstrate to a variety of users the validity of the Spacelab pallet-only mode and the performance of the Instrument Pointing System. The experiments included in the payload are listed in table 3.

Table 3 *Spacelab 2 Investigations and Principal Investigators*

Investigation	*Principal Investigator*
Solar Physics	
Solar Magnetic and Velocity Field Measurement System	Alan M. Title Lockheed Solar Observatory
Coronal Helium Abundance Spacelab Experiment	Alan H. Gabriel, J. Leonard Culhane United Kingdom
Solar Ultraviolet High-Resolution Telescope and Spectrograph	Guenter Brueckner Naval Research Laboratory
Atmospheric Physics	
Solar Ultraviolet Spectral Irradiance Monitor	Guenter Brueckner Naval Research Laboratory
Plasma Physics	
Ejectable Plasma Diagnostics Package	Louis A. Frank University of Iowa
Vehicle Charging and Potential Experiment	Peter M. Banks Stanford University
Plasma Depletion Experiments for Ionospheric Radio Astronomical Studies	Paul A. Bernhardt Los Alamos National Laboratory; Michael Mendillo Boston University
High-Energy Astrophysics	
Elemental Composition and Energy Spectra of Cosmic Ray Nuclei	Peter Meyer Dietrich Muller University of Chicago

Table 3 *Spacelab 2 Investigations and Principal Investigators (cont.)*

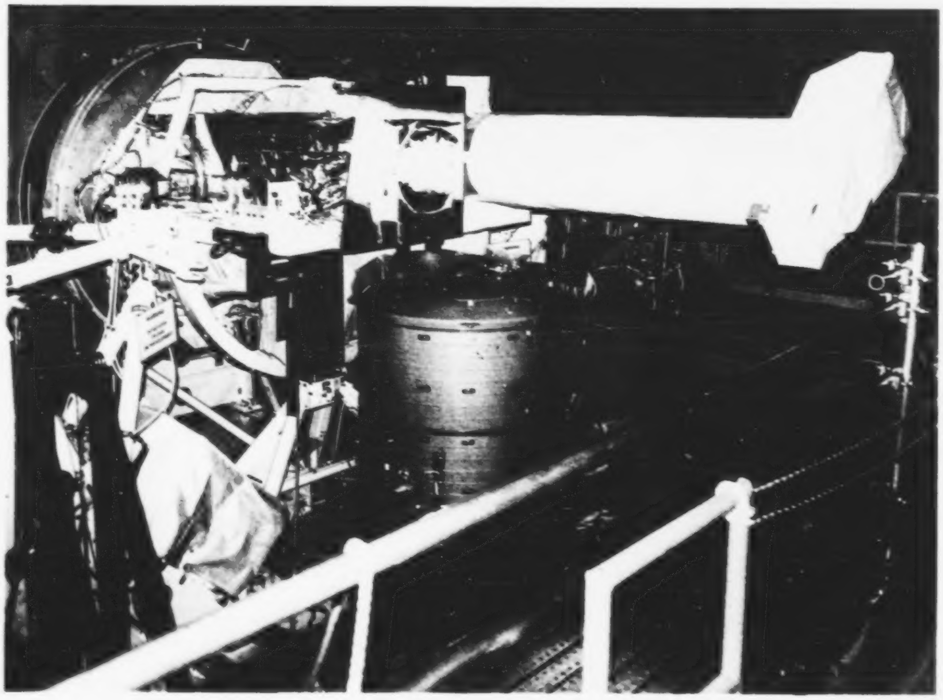
Investigation	*Principal Investigator*
Hard X-Ray Imaging of Clusters of Galaxies and Other Extended X-Ray Sources	A. Peter Willmore United Kingdom
Infrared Astronomy	
A Small Helium-Cooled Infrared Telescope	Giovanni G. Fazio Smithsonian Astrophysical Laboratory
Technology Research	
Properties of Superfluid Helium in Zero Gravity	Peter V. Mason Jet Propulsion Laboratory
Life Sciences	
Vitamin D Metabolites and Bone Demineralization	Heinrich K. Schnoes University of Wisconsin
Gravity-Influenced Lignification in Higher Plants	Joe R. Cowles University of Houston

More than 60 Co-investigators would assist the Principal Investigators in the operation of the experiments and in data analysis. Again, several members of the crew were directly involved in the development of some of the instruments: Payload Specialists Loren Acton and George Simon as Co-investigators on the solar optical universal polarimeter to be used in the solar magnetic and velocity field measurement system, Payload Specialist John-David Bartoe as Co-investigator on the high-resolution telescope and spectrograph, and Payload Specialists Bartoe and Dianne Prinz as Co-investigators on the spectral irradiance monitor.

Except for the two life science experiments, which would be conducted from the Orbiter crew compartment, and the plasma depletion experiments, which involved ground-based observations of the effects of Orbiter thruster firings, all scientific instruments of the payload required direct exposure to space. On the first pallet (shown in fig. 140), three solar instruments and one atmospheric instrument were mounted on the Instrument Pointing System. One plasma physics instrument, an electron beam generator, was also mounted on the first pallet. The second pallet held a large double X-ray telescope and three plasma physics detectors. The third pallet supported the infrared telescope, the superfluid helium technology experiment, and the small plasma diagnostics package which had been carried on the earlier OSS-1 pallet. In addition to the three-axis gimballing of the four instruments mounted on the IPS, the X-ray telescope gimballed around two axes (preventing a collision with the IPS was an important design constraint), and the infrared telescope swivelled from side to side around one axis. On this mission, the plasma diagnostics package would be permitted to fly freely while the Orbiter performed a series of intricate maneuvers around it to gain a more complete picture of the plasma field surrounding the Orbiter. Behind the third pallet, the huge egg-shaped cosmic ray detector was mounted on its specially designed support structure that was tilted to increase the detector's exposure to space (fig. 141).

As were its predecessors, the Spacelab payload had been under development for many years under the sponsorship of the NASA Office of Space Sciences and Applications. Each experiment had to satisfy two fundamental requirements: it must promise meaningful scientific results and be suitable for flight on the Shuttle. The candidate experiments were then narrowed down to a select few in a tough competition judged by the proposing scientists' peers. Spacelab 2 had progressed through a

Figure 140. The Instrument Pointing System carrying three solar instruments and one atmospheric instrument is mounted on the first Spacelab 2 pallet, with some of the instruments overhanging the igloo.



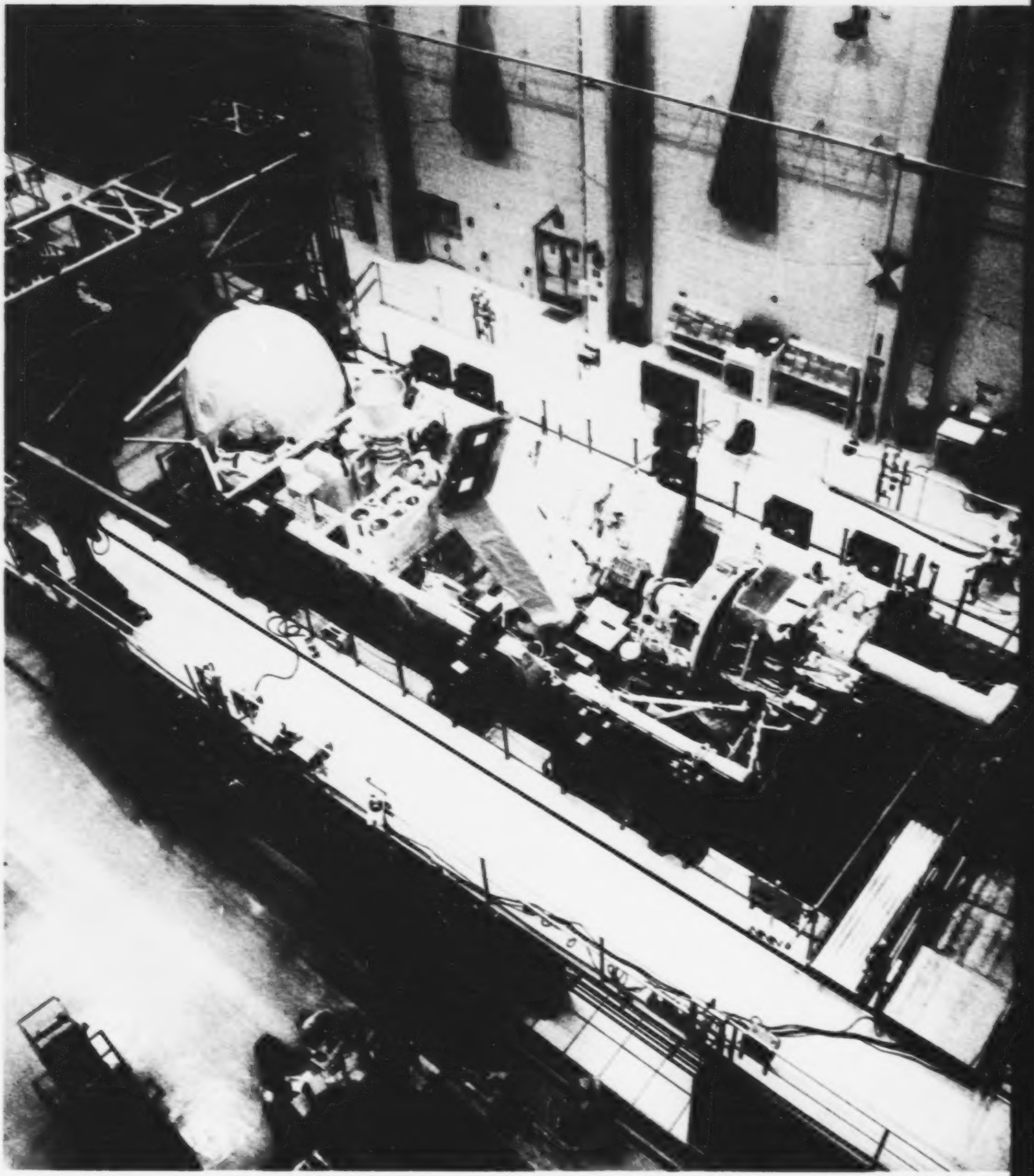


Figure 141. The fully assembled Spacelab 2 payload in the Level III/II workstand at Kennedy Space Center. Note the single pallet with its Instrument Pointing System and telescopes, the double pallet with its variety of instruments, and the egg-shaped cosmic ray detector.

succession of NASA Headquarters Payload Program Managers, beginning with Bill Witt, followed by Roland Chase, Ed Fleischman, and, finally, Lou Demas, who guided the program through the flight phase. In a parallel fashion, Drs. Jeffrey Rosendhal, Edward Weiler, and Daniel Spicer served as Headquarters Program Scientists during the life of this payload. Again, Marshall provided technical leadership for preparation of the payload, with Roy C. Lester as Mission Manager and Dr. Eugene W. Urban as Mission Scientist and chairman of the important Investigators Working Group.

THE FLIGHT CREW

Once again, a seven-person crew had been selected and trained for the Spacelab 2 mission, officially designated Shuttle mission 51-F. Col. C. Gordon Fullerton, who had been Pilot on the third Shuttle mission (which carried the OSS-1 payload) would be Commander of the mission, with Col. Roy D. Bridges, Jr., making his first flight, as Pilot. Dr. Story Musgrave, who is a medical doctor (and holds seven academic degrees) and who had been a Mission Specialist on the sixth Shuttle flight, would be a Mission Specialist again, although on this flight he would work with the Commander and Pilot to handle the busy schedule of Shuttle operations. Dr. Anthony W. England, a geophysicist in Earth and planetary sciences, and Dr. Karl G. Henize, a specialist in ultraviolet astronomy, were the Mission Specialists dedicated to operation of the Spacelab and its payload. Henize, who would be the oldest person to fly in space (58), had been waiting 18 years for his first flight opportunity and had been working with this payload from its inception. Dr. Loren Acton, an astrophysicist with Lockheed, and Dr. John-David F. Bartoe, an astrophysicist with the Naval Research Laboratory, would be the Payload Specialists on board. Their backups would be Dr. Dianne Prinz, a research physicist with the Naval Research Laboratory, and Dr. George Simon, a physicist with the Air Force Geophysical Laboratory. Bridges, Henize, and Acton would make up the Red Team and alternate with Musgrave, England, and Bartoe, constituting the Blue Team, in order to conduct 24-hour operations. Fullerton would be available to participate in all critical periods of the mission. The Spacelab 2 crew is shown in figure 142.

Spacelab 2 was expected to be a very busy mission for the flight crew. In addition to the normal operations, they would have to make many maneuvers to meet the solar and celestial viewing requirements and to deploy, fly around, and retrieve the plasma diagnostics package. There would also be engine burns above designated ground sites for the plasma depletion studies. The Payload and Mission Specialists, although professional scientists, had been trained to ensure the success of each investigation, first in the laboratories of the Principal Investigators, and then in the Spacelab 2 mockup in the Payload Crew Training Complex at MSFC. The entire crew had trained for hundreds of hours, not only in these facilities but in mission simulations using the training facilities at JSC. Also, in what proved to be some of the most valuable training, the science crew assisted in the hands-on integration and

Figure 142. The Spacelab 2 crew don sunglasses to spoof the significance of their solar mission, as they pose in the Orbiter crew compartment. Clockwise from Commander C. Gordon Fullerton (in striped shirt) are Dr. John-David Bartoe, Dr. Story Musgrave, Pilot Roy Bridges, Dr. Karl Henize, Dr. Loren Acton, and Dr. Anthony England.

checkout of the payload, Spacelab, and Orbiter at KSC. The crew was more than ready for this mission.

THE MISSION

Launch of the Spacelab 2 mission was scheduled for 4:30 p.m. EDT, July 12, 1985, and the trajectory was planned to put the Orbiter in a 208-nautical-mile orbit at 49.5° inclination. The countdown proceeded smoothly, the main engines were ignited, and then just 3 seconds before the firing of the solid rocket boosters and a launch commitment, the launch processing system sensed something was wrong and commanded the engines to shut down. There was deathly silence on the pad and in the viewing stands, but the water sprays quickly came on to cool the engines and the ground crew took the necessary steps to safeguard the flight crew on board. There was no panic, although Commander Fullerton told reporters later: "It was the longest 3 seconds I've ever experienced."

Once the crew was removed from *Challenger*, government and contractor teams descended on the No. 2 engine, removing the mechanical devices and components which could have triggered the shutdown. Although this was only the second pad abort for the Shuttle and followed on the heels of seven successive launches that seemed increasingly trouble-free, there was serious concern about this failure. Exhaustive investigation, however, seemed to indicate that this abort may have been caused by a momentary hangup of an engine component, rather than an actual failure. The launch was rescheduled for July 29, and crews began servicing the Shuttle, the Spacelab, and its payload for another launch attempt. Unfortunately, the checks on the Spacelab revealed a serious problem: one of the three computers would not work. This was the latest in a series of failures by the French-built Spacelab computers both in ground tests and in the Spacelab 3 mission, and was a matter of major concern. As you may remember, an early decision had been made not to provide igloo access on the launch pad for changeout of such failed components, and in this mission the location of the telescopes on the Instrument Pointing System (overhanging the igloo) would have made this an impossible operation. After much agonizing appraisal, the decision was made to launch with only the two Spacelab computers in operation. If one of them were to fail, very little science data would be obtained from the mission, although the prospects of obtaining the verification flight test data on the Spacelab systems still would be fairly high. The cost and time delay to the Shuttle schedule to install a new computer now were prohibitive. The risk would have to be taken.

Optimum launch time was 3:23 p.m., but it was missed when mission controllers had to dump, reload, and restart the software program in the Shuttle backup flight system. Finally, launch occurred at 5:00 p.m. EDT on July 29, 1985. Then, after almost 6 minutes of flight, this trouble-plagued launch encountered a new problem, the shutdown of one of its main engines. A courageous real-time decision by an engineer in Mission Control at JSC prevented shutdown of a second engine. Fortunately, the Shuttle was at a point in its trajectory when it could achieve an abort to orbit, and the crew took the necessary steps to implement this option. The resulting orbit was at an altitude of 170 nautical miles, somewhat lower than planned, and a considerable amount of onboard fuel had been jettisoned, restricting the number of orbital maneuvers which could be conducted. On the encouraging side, it appeared that only the helium abundance experiment would have its scientific objectives degraded at the lower altitude.

From the outset of the mission, the Instrument Pointing System would challenge the crew and its ground support team (fig. 143). At first the problem appeared to be that the search angle was overly constrained, so it was relaxed. Then a new problem appeared with a filter in the optical sensor package which focused on the Sun and stars to give the pointing system its intelligence for aiming its four experiments. Then it appeared that there were some errors in the software for converting Orbiter attitude into gimbal angles. Then there was a problem with some computer-generated bright spots in the optical sensor package that saturated the reference stars. Fortunately, on the third day it was discovered that the IPS operating mode designed to bypass the optical sensor package by using reference inputs from the experiments worked well, so scientific observations could be made when the troubleshooting was interrupted. Periodically it would seem the entire system was performing properly, and then new problems would appear. The ground crews made numerous proposals and the onboard crew tried everything. In fact, there were simultaneous problems which made troubleshooting very difficult and particularly frustrating to the crew. Meanwhile, other investigations were under way, achieving a rich cache of scientific data that delighted the investigators on the ground in the Payload Operations Control Center. Fortunately the two Spacelab computers were working perfectly and there appeared to be no problems with the igloo in its first mission. The plasma diagnostics package was released into an independent orbit (fig. 144) and *Challenger* moved off about a quarter of a mile and rotated around it. The X-ray telescope gathered data on the radiation spewed out from the massive star fields of Virgo and Centaurus. The electron beam gun was fired and the astronauts reported they could see the flashes of light as the beam followed natural magnetic lines to the co-orbiting plasma diagnostics package. On the lighter side, the amateur radio buffs on board, England and Bartoe, using an upgraded version of the ham radio operated on Spacelab 1, were successful in communicating with ground operators, including transmission of a video still picture to the JSC Amateur Radio Club.

For the next several days, the crew continued to focus on troubleshooting the IPS in collaboration with an international team of experts located in the Huntsville Operations Support Center at Marshall. The three large electrical drive units worked perfectly, as did the very complicated mechanical system of cables, actuators, pulleys, and clamps used to secure the delicate gimbal system bearings and the scientific instruments during launch and landing operations. The computers and the rate gyro package also worked fine, and the control system software worked the way it was programmed. Unfortunately, some of the programming, including some of the mission dependent parameters, was wrong. In particular, there were software problems related to the optical sensor package as well as a hardware failure of one of the two star trackers. The IPS worked as it was supposed to when it utilized one of the science telescopes rather than its own optical sensor package for pointing instructions.

In the meantime, the plants on board were growing nicely and the decision was made not to boost the Orbiter to a higher altitude closer to that planned for this mission. The infrared telescope was now operating and obtaining new readings about the heat energy of distant stars. One of the four instruments mounted on the IPS was not operating, but data were being obtained on all others. Then it appeared that the IPS had finally responded to the many changes and was working perfectly. It precisely aimed its three solar telescopes at specific spots on the Sun and held them there for minutes at a time (fig. 145). An analysis of pictures beamed to the ground showed a giant sunspot and huge arcs of gas (prominences) indicating that the IPS was able to track the Sun with only barely detectable jittering. With this positive report and the fact that expendables for the fuel cells were not being depleted as fast

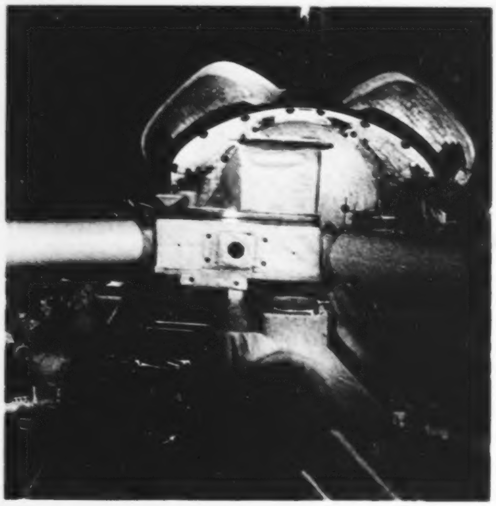


Figure 143. On-orbit view from the Orbiter crew compartment looking into the cargo bay on Shuttle mission STS 51-F (Spacelab 2). The Instrument Pointing System has not yet been deployed.

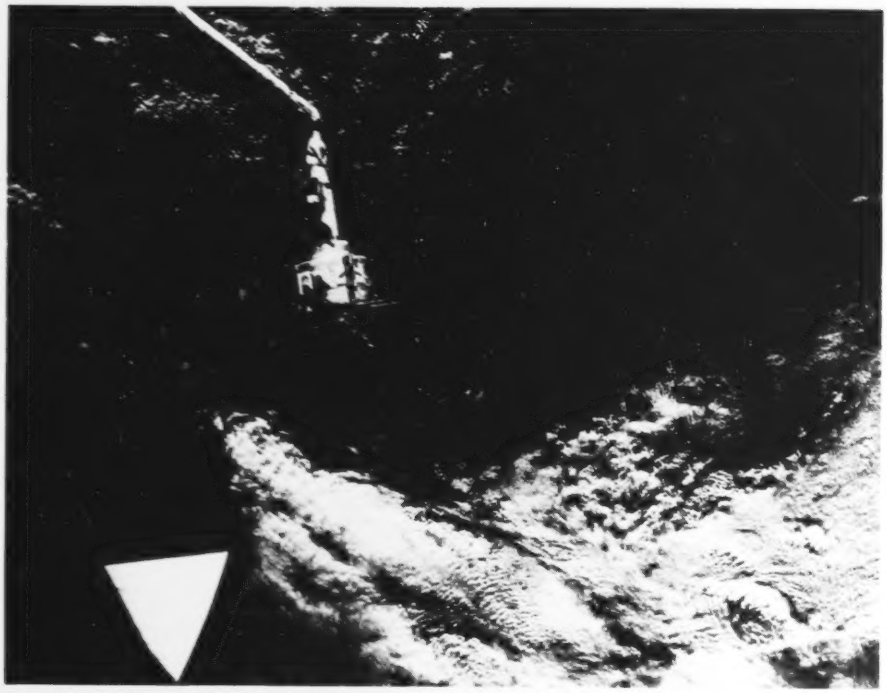


Figure 144. The plasma diagnostics package is held by the manipulator arm of the Orbiter *Challenger* before being released to fly unattended.

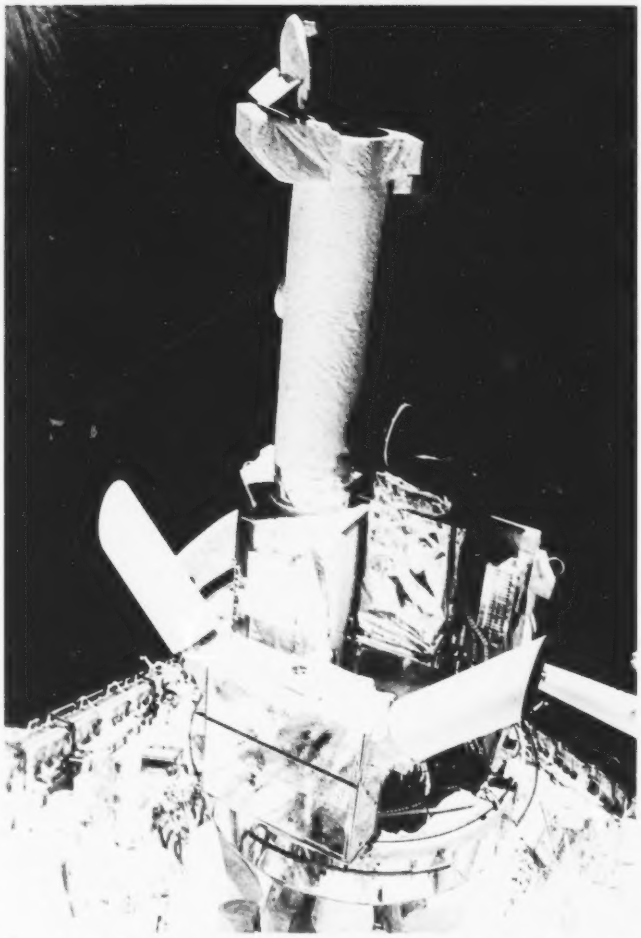


Figure 145. The Instrument Pointing System deployed. Note the disc-like sun shields open on two of the instruments.

as expected, an extra day was granted to the planned 7-day mission. The crew was now conducting a nonstop survey of the Sun, studying flares, sunspots, and other phenomena. When the solar optical univeral polarimeter suddenly and unexpectedly came to life on Sunday, the extra day on orbit promised to prove doubly productive before the planned return to Earth on Tuesday. Mission Scientist Urban forecast that the mission would accomplish 80 to 85 percent of its objectives.

After its problem-shrouded launch and mission, the return to Earth seemed routine, landing on Edwards Air Force Base Runway 23 at 12:45 p.m. PDT, August 6, 1985. Jesse Moore, now NASA's Associate Administrator for Space Transportation, told reporters that, despite problems on the flight, Spacelab 2 "returned a wealth of information. In fact, this may be the most important scientific mission that the Shuttle has flown."

MISSION AFTERMATH

Postflight analysis quickly focused on the Instrument Pointing System and its performance, in view of its planned use for observing Halley's Comet during the next year (a plan that would be canceled following the *Challenger* disaster in January 1986). Despite the problems during the mission, however, more images of the Sun from space (and in greater detail) were obtained than in 171 days of manned Skylab observations in 1973–1974. It appeared that erroneous software had been the principal culprit in the early problems with the IPS. The first error caused the optical sensor to seek a Sun much brighter than it actually is. A second error was found in the level of background illumination the system would accept. On the third day of the mission an error was found involving how the optical sensor package and the Spacelab subsystem computer communicated. It was not until the seventh day that the fourth error was found involving how the IPS roll angles and mass memory data in the computer were interacting. The net result of these problems was that initially the IPS could not find the Sun. When that problem was solved, the IPS refused to remain in a "fine tracking" mode of operation. Finally even after software changes were made to keep the IPS in fine tracking, it took a very long time to acquire a particular target. The acquisition time was on the order of 4 to 5 minutes, and, without upgrading the computer system, it will not improve. One other point to be noted about IPS performance was that the disturbances from crew motions were greater than expected. Although the mass of a crew member seems insignificant when compared with the mass of the Orbiter, crew activities, including floor and wall pushoffs, create significant errors in the pointing. Fortunately, these errors tend to damp out quickly. It appeared that the IPS, whose complexity had been so underestimated throughout its development period, continued to act true to form in its first flight trial. Despite these problems, there was reason for optimism that the pointing accuracy was better than the design specification and the system would be able to support its proposed future uses. The flight crew and the international team of industry and government experts at the Huntsville Operations Support Center deserve great credit for unravelling the several causes of the IPS operational problems and straightening them out under the pressure-cooker conditions of a mission in progress. Ray Tanner, the Spacelab Program Deputy Manager, is singled out, in particular.

There were many operational and scientific highlights in this third Spacelab mission. Almost 13 000 commands were transmitted to the Orbiter, exceeding any previous Shuttle flight by 50 percent. Approximately 1.25 trillion bits of data were transmitted to the ground, requiring 230 miles of magnetic tape to store. The Lockheed telescope, operating only near the end of the mission, achieved only 16 hours of its planned 50 hours of observing time, but was able to shoot all 12 800 images in its film magazines. It was able to focus on solar locations and acquire high-resolution images every 2 seconds for periods as long as 40 minutes. The high-resolution telescope used all 4150 film images loaded in its film magazines and collected data on 20 orbits as compared with only 16 minutes of sounding rocket observation time achieved with this type of instrument over the previous 10 years. Bartoe was able to observe the rise and fall of spicules on a precise schedule and to conduct a systematic search of the solar disc for coronal bullets. The helium abundance experiment obtained 70 percent of the data needed to record the helium abundance in the Sun, although the quality of data was less than anticipated because of the reduced altitude.

The infrared telescope, cooled by cryogenic helium, had most of its wavelength capabilities saturated throughout the mission, raising serious concerns about the feasibility of infrared measurements from the Orbiter, which may cause too much background radiation. This will require further evaluation. Four of the eight burns by the orbital maneuvering system engines were performed for the plasma depletion tests, despite the limited propellant remaining on board. These burns were found to be effective in opening holes in the ionosphere for ground-based observations. The measurements with the plasma diagnostics package were spectacularly successful with 70–100 percent of the mission objectives achieved. The superfluid helium experiment also achieved 80–100 percent of its objectives. The University of Chicago's 4330-pound cosmic ray detector received about 100 impacts per second and promised a bonanza of data for later ground analysis.

The verification flight test objectives, including the overall performance of the Spacelab subsystem, although the primary objectives on this mission, were almost forgotten in the desire to obtain scientific data and to make the IPS respond to the investigators' needs. The final achievement of scientific observations using the IPS was a tremendous technological achievement. It was also demonstrated beyond a shadow of doubt that the pallet-only mode provides a unique capability for Spacelab's scientific users. Whether there would be many scheduled uses of this mode in the future, as opposed to the module configuration, remains to be seen. For those members of the Spacelab team who had started with the initial configuration, however, and pursued the design and development through the successful flight tests, this was a gratifying conclusion to a program unique in the annals of space history. The Spacelab development program had been successfully completed, and all could take satisfaction in its accomplishment.

Personal Reflections

I could not have been more excited about the Spacelab 1 launch had I still been directing the program. Of course it would have been interesting and rewarding to sit in the Launch Control Center and feel direct responsibility for the success of the mission, but I had long before recognized the fact that, at launch time, the high-level managers are little more than window dressing. The people with technical know-how who must have control at this critical juncture are the ones that count.

The comments from dissidents in the public and scientific press were of great concern to me. I was proud of the achievements of the Spacelab team and resented those who in any way downgraded its efforts. Johnny-come-latelies who had all the answers and perfect hindsight and scientists who were still insisting that man was unnecessary for space research continued to pop up with their predictable comments and received far more recognition from the news media than they deserved. Not that I believed that everything we had done within the program was perfect; there obviously were shortcomings in the Spacelab system and in our managerial performance. On balance, though, I was convinced we had built a useful system for manned space science, and I was convinced it would work. There was little doubt in my mind that the verification flight instrumentation would confirm in flight what the qualification testing had already verified on the ground.

With respect to the first payload and its mission, many of us had questions. Had we been overly ambitious in our early planning and saddled the payload developers and mission planners with an impossible task? Would the ground and flight crew be too overloaded with experiments, interactive controls, and too many systems hooked together for the first time? Had the training been adequate? A complete end-to-end system check and mission simulation had been impossible to conduct because of the number of elements in the data linkup and the prohibitive cost to conduct such tests. Would everything work together over the planned mission period of 9 days? Finally, how would the people work together? There had been some bad feelings between the Spacelab and payload managements, and between the payload personnel on the ESA and NASA sides. Would they set aside their differences during this critical mission, and would the 100 or more scientists on the ground at Houston work as a team to get the most out of the mission? Could an MSFC mission management team located in the POCC work effectively with the JSC mission control team, and would the MSFC backup team in the Huntsville Operations Support Center prove to be more of a hindrance than a help? It was gratifying to see the positive answers and rewarding results of the first mission.

My own experience with the first flight crew was very limited. Except for Parker and Garriott, I did not know any of the crew personally, although I had met all of the science members of the crew at various times. I knew Young by reputation as an individualist, but a very competent and tested flight commander. In general, I was convinced it was a good crew and certainly one which had had adequate time to prepare for its mission. To operate around the clock with only two shifts, however, would not be easy.

On Saturday night, November 26, NASA held a reception for the Manned Space Flight Awareness Program honorees at the Visitors Information Center at KSC. This tradition at manned space flight launches, which recognizes important contributors to the program who would not normally be singled out by the news media, has become an important occasion on many Shuttle launches.

On Sunday night, November 27, the invited guests of ESA Director General Quistgaard and NASA Administrator Beggs were taken on a tour of the launch pad area and then briefed at the KSC Training Center. In addition to welcoming remarks from the agency heads, a mission readiness status was given by backup Payload Specialist Wubbo Ockels. The guests were then taken to the Visitor Information Center for a final reception, during which Beggs presented Quistgaard with a painting of Spacelab commissioned by NASA and created by artist Charles Schmidt. On receiving this gift, Quistgaard quipped, "Now we're going to take a painting the other way—across to Europe. You in the United States take most of our good paintings."

The reunion of old friends was especially rewarding. Jean Albert Dinkespiler and Hans Ortner, two of our earliest contacts on the program in Europe, were delighted to be present. The picture in the local paper of the VIP stands at the moment of liftoff showed Kenny Kleinknecht, our former Paris representative, and Jacques Marchal, Bignier's program controller, right in the front row. These two had become good friends during Kenny's years in Paris. Almost every one of the Local Project Managers from each of the Spacelab European co-contractors was there to share in the moment of triumph, as were Bill Rector and Don Charhut, the early leaders of the TRW and McDonnell Douglas teams in Europe. Heinz Stoewer, the first ESA Project Manager, also participated in the activities. Near the countdown clock stood three poles with the U.S. flag and the agency flags of NASA and ESA. As the Shuttle lifted off, I made certain that my telephoto lens framed the streaking vehicle with the three flags that so appropriately reflected the cooperative nature of this program. It was truly a banner day.

That afternoon I was delighted to attend a reception sponsored by the McDonnell Douglas Technical Services Company at the Patrick Air Force Base officers club. My former NASA boss, John Yardley, was now President of MDTSCO in addition to his primary job as President of McDonnell Douglas Astronautics Corporation in St. Louis. It was good to see him and to recognize MDTSCO's remarkable performance in support of the Spacelab program. Under the overall leadership of Jake Jacobsen and Dale Steffey at Huntsville and George Faenza and Ed Scully at KSC, this Spacelab service contractor had done an outstanding job, starting with nothing and breaking new ground all along the way. Now it was ready to support continuing Spacelab operations.

Following the MDTSCO party, we headed for another party sponsored by the newly merged West German aerospace company, MBB-ERNO. It appeared that the Spacelab development contract loser had essentially taken over the winner—or had it? Although ERNO was the subordinate partner in the merger, it apparently would retain most of the space effort in Bremen, and its prime Spacelab mover, Hans Hoffmann, had survived the changes and emerged in a key position in the new company. The party was more like one of the old-time launch parties at the Cape: everybody who heard about it came, and there was no attempt to control the attendance as several hundred guests milled around the old Hacienda de Sol mansion on Merritt Island, stood in interminable lines for refreshments, and enjoyed the excitement of the occasion. It had been a great day, and all the reports from outer space were positive.

When it came to onboard repairs during the first Spacelab mission, I recall the words of former Skylab astronaut Ed Gibson when he was at ERNO: "The most valuable tool on board Skylab was the hammer." In Spacelab 1 it turned out to be a small multipurpose tool kit that included screwdrivers and pliers. Skeptics could easily say that the components should have been designed and built to not fail, but the fact is they did fail, and only the quick and innovative work of the crew using improvised work areas and tools saved the day.

One of the most peculiar reports from the crew was about periodic Spacelab "bangs." At first it appeared that the module was expanding or contracting with a kind of oil-can effect. Later analysis and correlation with the verification flight measurements indicated that the probable cause was movement of the keel fitting due to changes in thermal loads. In any case, when a "bang" occurred, it was a bit disconcerting to the crew in the module. Other than that, the noise in the module was minimal and communications were conducted in a normal tone of voice.

The final results of the Spacelab 1 mission, both from the Spacelab and the payload perspectives, are nothing short of amazing. It is hard to have envisioned a more satisfactory outcome on this first flight of the Spacelab system. In many ways, the Spacelab 3 mission was very similar to the first mission and there were no major surprises. In actuality, the focus of the second mission on a few selected disciplines and a much smaller number of experiments did not provide as striking a difference in results as might have been anticipated. As in most manned missions, a motivated crew will drive itself to the point of exhaustion in a Shuttle-duration mission, knowing it has trained extensively for this brief period and wanting to obtain every possible bit of scientific value out of its onboard instruments. However, in the case of Spacelab 3 one would have to question the motivation of this particular crew toward animal experiments in space. The crew seemed to have very low tolerance for the problems it encountered in this area. On behalf of the crew, however, it could be argued that the animal facility should have been designed with better understanding of potential operational problems.

The Spacelab 2 mission appeared to have been the most difficult of the first three flights, probably because of the dependence on the Instrument Pointing System and the difficulties in obtaining reliable and predictable IPS performance. I liked the confidence exemplified by our MBB-ERNO friends in placing a full-page ad in the July 15, 1985 issue of *Aviation Week and Space Technolgy* magazine, announcing to the world that Spacelab 2 had just been launched aboard the Space Shuttle *Discovery*. Even though the Spacelab 2 launch had been aborted on July 12, and the Spacelab was still nestled in the cargo bay of the *Challenger* (not the *Discovery*) on the ground, one had to admire the spirit with which this outstanding European consortium assumed that what had been planned would be successfully implemented. Things did not always happen the way they were planned in the Spacelab program, but ERNO was right—the program did accomplish its goals, and in a way that has made us all very proud.

12 Lessons Learned

ANTICIPATION VERSUS REALIZATION

Now that the Spacelab development program has been completed, it is time to look back and to review the lessons of this remarkable joint venture. I have chosen the outline of the Memorandum of Understanding (MOU), signed by NASA and ESRO (ESA) at the beginning of the program, as a framework for review, and I will consider the accomplishments of the Spacelab program compared with the expectations expressed in the MOU when the program was initiated.

OBJECTIVES

The overall objectives of the program were for ESRO (ESA) to design, develop, manufacture, and deliver the first flight unit; to use the Spacelab as an element of the Space Shuttle system; for Europe to have access to the system; and for NASA to procure additional production units. All these objectives were achieved, without question, although the way they were achieved was not always satisfactory to both sides. The Europeans would have been happier if the development costs had been less, if the conditions for access had been more favorable, and if NASA had procured more follow-on flight units. On the other hand, NASA would have been happier if it had not been required to develop so many peripheral items of hardware and software, if the integration with the Space Shuttle had not become so expensive from an operational standpoint, and if Europe had established a more substantive program of Spacelab utilization. Still, all in all, one would have to conclude that the program's overall objectives were fully met.

GENERAL DESCRIPTION OF THE PROGRAM

The description of mannable laboratory modules and unpressurized instrument platforms in the MOU accurately portrays the Spacelab module and pallets that were developed, albeit with a versatility of use that far exceeds the original concept. In only two respects has the resulting design not measured up to users' early expectations: minimum cost and rapid access. Both matters have been discussed earlier in some detail, and attempts are still being made to improve the system in both regards. However, as noted, in some respects the Spacelab is captive to factors beyond its control in meeting these expectations, e.g., the reduced frequency of Shuttle flights and the escalated cost per flight. In at least two aspects the final Spacelab design does have shortcomings which contribute to high operational costs and limit its usefulness. The first problem is that making the system so versatile actually complicated the design in order to provide for configuration possibilities that may seldom, if ever, be used. The second problem is caused by the rapid advance in avionics systems and the lack of planning in the Spacelab design to take advantage of these advancements.

Most of the expectations about the interface with the Shuttle described in the MOU have been fulfilled, although this interface was one of the most serious technical challenges to the program, and the development of two such complicated systems in parallel introduced many complications. The idea of optimizing the commonality of components between the Spacelab and Shuttle, also suggested in the MOU, proved to be naive.

It was proposed from the outset that the Spacelab would provide for maximum user involvement and accessibility and for users to utilize all or portions of the Spacelab in combination with other users to accomplish a wide spectrum of missions. Certainly the provision of standard resources by the Spacelab and the flexibility of equipment and mission structuring has surpassed the most ambitious early expectations.

PHASING AND SCHEDULING

The MOU outlined a program starting with Phase B studies and resulting in a delivered flight unit 1 year before the Shuttle would become operational. Both parties were to keep the other fully informed of factors affecting their respective schedules. Although there were substantial schedule slips on both sides, these objectives were more than met. There may have been times when the news media seemed to react faster than our telephone lines between Paris and Washington, but in general there was adequate warning with respect to overall schedule changes.

PROGRAM PLANS

This section of the MOU required both sides to develop a joint program plan to amplify in greater detail the descriptions of the Spacelab system and the phasing, scheduling, and working arrangements for the program. Such a plan was developed and served as a mechanism for assuring that the two agenices were in agreement on the steps to be taken in developing the overall system. Once completed, however, its importance was soon diminished as the Program Requirements Document, System

Requirements Document, Systems Specifications, and other implementing documents were formulated. The establishment of a Spacelab documentation tree was, however, an essential outgrowth of this effort.

RESPECTIVE RESPONSIBILITIES

This section of the MOU was probably the most detailed of the entire document. It specified that ESRO (ESA) was to deliver one flight unit, one engineering model, two sets of ground support equipment, initial spares, drawings, documentation, and additional items that might be added; establish liaison; provide interface data and progress and status information; maintain and fund sustaining engineering through two missions; ensure NASA's availability of such support thereafter; ensure production for NASA procurement; and integrate its own experiments. NASA, for its part, was to establish liaison; provide technical and managerial consultation, technical interface information, and progress and status information; monitor progress in Europe; specify operational plans; conduct analyses; develop peripheral components; and manage all operational activities. Perhaps the most important aspect of this section was that it provided for the addition of new items as needed. Probably the major fault was the failure to mention the subject of logistics, an omission that required considerable negotiation and was the source of much anguish for the Program Directors.

COORDINATION/LIAISON/REVIEWS

The MOU required each agency to designate a Program Head and Project Manager and to utilize a joint Spacelab working group for coordination of program activities. Liaison was to be provided by both sides, along with membership on each other's change control boards, and regular progress reviews were to be open to both groups. Finally, an annual review was to be conducted by the NASA Administrator and the ESRO (ESA) Director General.

As we have seen, all these provisions were carried out fully and provided an effective management relationship, particularly during the early phase of the program. As the early Spacelab missions approached, the NASA side of the interface was complicated by the establishment of a separate Spacelab payload and mission planning office within the Office of Space Sciences, so that the ESA Program Director had to work with two NASA Directors.

FUNDING

NASA and ESRO (ESA) were each to bear the full costs of their respective responsibilities and carry out their commitments subject to their respective agency funding procedures. Neither party was to seek to recover research and development costs in the development of items procured from the other. These commitments were honored. However, as ESA's program costs approached first 100 and then 120 percent of the initial estimate, ESA made strong efforts to curtail the program or transfer responsibilities to NASA in order to reduce its funding obligations. The concept of an open-ended commitment to a development program of this nature seemed to be unheard-of in Europe, and ESA was continually seeking to establish an upper limit to its commitment which would be acceptable to NASA. In our thinking, the commitment was a program commitment rather than a specific cost commitment. On the other hand, ESA found it difficult to understand that NASA's commitment had to be on a year-by-year basis, this because of the nature of the congressional budget process which requires NASA to receive authorization and appropriation of its funding each year.

NASA PROCUREMENT OF SPACELABS

This section of the MOU turned out to be one of the most controversial areas in the program. It consisted of three basic agreements: (1) NASA would procure from ESRO (ESA) whatever units it needed after the first flight unit, (2) NASA would refrain from the development of any system "substantially duplicating the design and capabilities of the Spaclelab," and (3) NASA would give ESRO (ESA) advance notice of any prospective requirements for substantially modified or new Spacelabs. The first of these agreements (procurement of additional units) was fully honored, however the disappointment in Europe was that only one Spacelab was procured by NASA and this after considerable haggling about the price, an attempt at a barter arrangement in lieu of direct financial payments, and delays in placing the order that created a hiatus in the production schedule for some members of the European production team. The second agreement (duplication) caused many problems throughout the program until finally resolved by the negotiations of the Duplication Avoidance Working Group described in chapter 8. "Substantial duplication" turned out to be a loose definition that could be interpreted in a variety of ways. As far as the final commitment in this section (advance notice of new requirements), some Europeans would argue that NASA was remiss in not seeking European development of such items as the MPESS (or T-structure). On the other hand, NASA and ESA conducted extensive discussions of the options for follow-on development, and if it were not for the escalating interest in Space Station development, it is probable that "substantially modified" Spacelabs would have been developed in some cooperative manner.

CONTINGENCIES

This section of the MOU describes the actions to be taken in the event that the Spacelab could not be delivered by Europe or that components and spares would not be available to NASA. It also stated that NASA would listen to European concerns about Shuttle changes, but reserved NASA's right to make such changes, including those to the Spacelab/Shuttle interface. The first option turned out to be moot because ESA did deliver the Spacelab. However, recent problems with the Spacelab computer may yet cause problems in the component area. Because of several computer failures in testing and in flight, as well as the tremendous advance in the state of the art, NASA is considering replacement of the CIMSA computer. Naturally, ESA would like to have the replacement be European-made, and NASA, for operational efficiency, would prefer to consider U.S. manufacturers. With respect to Shuttle changes, NASA was most considerate of ESA's comments on planned changes which were discussed at meetings of the Shuttle Change Control Board. But the most significant impacts on the Spacelab from Shuttle changes came from the increased structural loads, which were simply facts of life that resulted from the test program, not proposals discussed by a change board.

ACCESS TO TECHNOLOGY

Both sides had agreed that technology would be made available to the other side as necessary to accomplish their respective tasks, that NASA would provide general information on the Shuttle, and that use of technology in other than Spacelab tasks would be considered on a case-by-case basis. Proprietary rights would be safeguarded, NASA reserved the right to provide assistance in the form of hardware as opposed to know-how, and NASA would provide assistance in arranging for services, export licenses, and use of U.S. facilities.

No discussion of the Spacelab program provides opinions as diverse as does the subject of technology transfer. Some will argue that there was no transfer whatsoever and that that was one of the biggest disappointments for Europe in the program. Others will argue that there was significant though not extensive technology transfer. Many export licenses were granted and technical assistance agreements issued. In only a few cases were such requests denied and these involved proprietary processes which would have given significant commercial opportunity to the other side. The licenses and agreements that were issued neither held up the program nor were detrimental to it, and they did not give data that detracted from a trade advantage. U.S. industry consultants to ERNO certainly provided significant transfer of knowledge. Similarly, technology was transferred by JSC/Rockwell studies sent to Europe as part of Shuttle interface discussions, by NASA personnel loaned to ESA, by NASA resident teams in Europe, by NASA participation in program reviews, through ESA and European contractor visits to the U.S., through U.S. citizens hired by ESA, and through ESA resident teams in the U.S. Probably the most difficult problems encountered in this area were the different interpretations of what was considered proprietary data in Europe and in the U.S., and the lack of availability of some detailed data from the European prime contractor's co- and subcontractors.

ACCESS TO THE USE OF SHUTTLE/SPACELAB

The issue of access was another controversial element of the Spacelab agreement. The controversy was not with the specific words written in the MOU, but rather with what was left unsaid about the cost for Europe's general use of the Shuttle itself. The Spacelab MOU focused on four points: joint planning of user requirements, European flight crew opportunities, use of the first Spacelab flight unit including a joint payload on its first mission and NASA's right to modify the unit, and use of the Shuttle for subsequent Spacelab missions and preferred access for European use of the Spacelab. One area which has generated much controversy has been the question of what was meant by the term "preferred access." Europe has repeatedly interpreted it to mean "reduced cost." As the cost of Shuttle flights has continued to increase, this subject has continued to be volatile. On the other hand, the MOU clearly stated that cooperative use of the first flight unit would be encouraged throughout its useful life, and NASA would consider making the Shuttle available for Spacelab missions on either a cooperative (non-cost) or cost-reimbursable basis. Perhaps if ESA had followed through with a more significant Spacelab utilization program, at least some of these missions could have been cooperative missions, resulting in significant cost savings to Europe.

PUBLIC INFORMATION, PATENTS, AND PROPRIETARY INFORMATION

Several agreements in the MOU pertained to the release of public information on the program and the respect of each other's patent and proprietary data rights. Public information policies were developed and honored by both sides, though not without a certain amount of difficulty at the time of the first (joint) Spacelab mission. Once the NASA Public Information Office accepted the fact that Spacelab had been developed by Europe and began to give full recognition to ESA and Europe in press releases for the mission, the problems diminished. Patents were never a problem within the program, and once the Proprietary Data Agreement was signed in October 1977, the proprietary data problems also disappeared.

SETTLEMENT OF DISPUTES

This section of the MOU identifies the NASA Administrator and ESRO (ESA) Director General as the persons who would settle any disputes in the interpretation or implementation of the terms of the cooperative program. Should they be unable to resolve such disputes, the issues could be submitted to another form of resolution or arbitration as might be agreed. Earlier chapters describe many cases where resolution of problems was taken to the agency heads. Fortunately, no issue was left unresolved at this level, so a higher level of arbitration was never needed.

DURATION AND ENTRY INTO FORCE

The final two articles in the MOU specify that the agreement would last for at least 5 years from the date of the first Spacelab mission but could be extended by mutual consent, and the agreement would enter into force as soon as signed by the NASA Administrator and ESRO Director General. There were no questions or problems about either provision. In fact, the agreement has now been extended to 1991.

PROGRAM SUMMARY

It is difficult to reduce the lessons learned from the Spacelab program to a select few. But if I were asked, I would recommend the following considerations for future cooperative agreements in the areas of development, management, and operations:

Development

1. Define the program in as much detail as possible before entering into formal agreement.
2. Understand and specify the documentation needed during the lifetime of the program.
3. Limit the amount of flexibility to be provided in the system design.
4. Include pathfinder hardware.
5. Understand the technology needs, and plan for the incorporation of advancements in the state of the art.
6. Insure the continuing production of additional units and spares.
7. Make sure the commitment is open-ended, not restricted by some artibrary cost ceiling or schedule.
8. Provide for a method to determine the reasonableness of costs.
9. Avoid vague commitments about refraining from duplication of effort.

Management

1. Establish a top-level working group to coordinate the program.
2. Select liaison personnel very carefully.

3. Plan for regular and meaningful progress reviews, fully shared.
4. Specify how any joint operations will be managed.

Operations

1. Design for maintainability.
2. Include specific logistics plans.
3. Specify in some detail any plans for joint usage.
4. Consider a user charge break in the access provisions.
5. Specify the operational support to be provided by the developer.

SPACELAB'S POLITICAL HERITAGE

It is interesting to observe the political climate with respect to future cooperative efforts in manned spaceflight that has developed since the end of the Spacelab development program. I have commented throughout this book about Europe's early expectations from its participation in post-Apollo activities, and I have traced the rise and fall in U.S. and European enthusiasm and support for the Spacelab program and for future utilization. We have observed many difficulties in the course of the program that could have destroyed this joint venture or at the very least undermined the spirit of cooperation among the participants. In comparing the early plans with the final fulfillment of the program, however, we see that there were many triumphs and very few real failures. Yet, since the end of the development program, the attitude of European and U.S. representatives toward future cooperation has become increasingly suspicious or combative.

What has happened to cause this change? Was the euphoria surrounding the Spacelab 1 and 2 missions only a transitory blush? Were there underlying hostilities and resentments waiting to surface as soon as the immediate challenge of Spacelab was overcome? Or are the less cordial relationships mainly the result of the more general political reality now that market competition is a major threat (and, at least in our case, the perception that the U.S. government gave away the (technology) store in the last 20 years)? Why are former participants in the Spacelab program such difficult negotiators today? Is NASA unable to accept the concept of ESA as an equal partner in the next venture? Were both NASA and ESA so overbearing and inconsiderate in their demands on each other during the course of the Spacelab program as to create a lack of trust for future joint programs? Why do so many people consider the Spacelab program as a negative example, as the way "not to do it"?

I do not pretend to know the answers to all these questions, nor do I know anybody who does. Looking back on the start of the Spacelab effort, I recall how we said, "Let's not make the mistakes that were made in Skylab." And now, Space Station planners are saying the same thing about Spacelab. Maybe it's only human nature to want to do better and to learn from past errors, and who could fault those goals?

OVERALL ASSESSMENT

It would be hard to argue with the conclusion that Spacelab development was accomplished successfully. The final design meets the requirements established, and Spacelab is a quality product that has been proven in ground and flight tests. The management organization provided clear lines of responsibility and authority and good communications. The parallel development of the Shuttle, the Spacelab, the Tracking and Data Relay Satellite System, and the Payload Operations Control Center, plus other peripheral systems and facilities required constant attention by the management team. MSFC proved to be an effective and responsible lead center for NASA. ESA and ERNO developed a competent technical and management team in Europe for the development of manned space systems. Relations between NASA and ESA were outstanding. Finally, in terms of program costs, ESA completed its part of the program within 140 percent of its original estimate, NASA's development program was completed within 169 percent of its original estimate, and the NASA follow-on procurement was only 25 percent of the first estimate, primarily because of reduced content and favorable dollar exchange rates.

No program is ever 100 percent successful, but if any international space effort is to be called a success, Spacelab qualifies. As a result, Europe now has a manned space system capability and the U.S. has an excellent manned laboratory system to use with its Space Shuttle.

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In writing this story of the Spacelab program, the author relied primarily on his personal records and the resources available in the NASA Headquarters Spacelab Program Office. These records generally fall in two categories: those of an ongoing nature (which are listed in summary fashion only) such as program reviews, committee meeting minutes, and newsletters, and those of a specific nature tied to a particular subject or point in time. Copies of most of these records will be filed in the NASA Archives following the completion of this project.

In addition, the author interviewed some 200 participants in the program, whose comments influenced in no small measure his conclusions and provided a valuable source of information in all areas of the program. Although it was impossible to interview every key individual who had an impact on the program, the author believes that those interviewed represented a reasonable cross-section of the management team.

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Interviews

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Kennedy Space Center

Don Bailey
Dick Bohlman
Jack Dickinson
Roger Gaskins
Bob Gray
Fred Head
Dean Hunter
Bill Jewell
Paul Kolasky
Gene McCoy
John Oertel
Bill Oyler
Tom Purer
Eldon Raley
Ernie Reyes
Ike Rigell
Bill Rock
Lamar Russell
Dick Smith
Wiley Williams

Marshall Space Flight Center

Fred Applegate
Jim Bishop
Dan Blenis
Charlie Brooks
Rick Chappell
Gene Compton
Harry Craft
Bob Crumbley
Carmine DeSanctis
Jim Downey
Jim Grubbs
Leo Hall
Pete Hall
Chris Hauff
Dick Heckman
L. Hendrix
Uwe Heuter
Ralph Hoodless
Bobby Jackson
O.C. Jean
Bill Johnson
Walt Kennedy
Jim Kingsbury
Jack Lee
Wayne Littles
Lou Logan
Bill Lucas
Bob Marshall
Max Nein
Carla Norton
Tony O'Neil
J.T. Powell
Luther Powell
Bob Spencer
Ray Tanner
John Thomas
Dick Tinius
Gary Wicks
Lowell Zoller

Johnson Space Center

Joe Allen
Don Bourque
Lee Briscoe
Glen Cress
Owen Garriott
Dan Germany
Charley Harlan
Al Holt
Chuck Lewis
Glynn Lunney
Jim Mager

Johnson Space Center

Lem Menear
Merlin Merritt
Dick Moke
John O'Loughlin
Bob Parker
Johnny Parker
Don Puddy
Carl Shelley
John Waters
Larry Williams

NASA Headquarters

Bill Armstrong
Dick Barnes
Bob Benson
Larry Chambers
Guy Cohen
Phil Culbertson
Charlie Donlan
Bob Freitag
Tom Hagler
Bill Hamon
Jim Harrington
Noel Hinners
Rod Johnson
Sam Keller
John Kelly
Bob Kennedy
Kenny Kleinknecht
Bob Lindley
Bob Lohman
Chuck Mathews
Garland McCoy
Jesse Moore
Jim Morrison
Pat Murphy
Dale Myers
Bobby Noblitt
Ken Pedersen
Charley Pellerin
Gil Roth
Al Ryan
John Sakss
Mike Sander
Bill Schneider
Gerry Sharp
Mary Jo Smith
Stan Weiss
Bob Wojtal
John Yardley

McDonnell Douglas Technical Services Company

Ed Bonnett
George Faenza
Jake Jacobsen
Bill Lokken
Ed Scully
Dale Steffey

Goddard Space Flight Center

John Busse
Ted Goldsmith
Ken Kissen

McDonnell Douglas Astronautics Co.

Hal Bauer
Don Charhut
Merrill Toles
Dave Wensley

Rockwell International

Hal Emme
Donald Bryce Thompson

TRW

Bill Rector
Dolph Thiel

General Dynamics

George Drake
Dennis Powell
Wally Withee

U.S. Department of State

Bill Bastedo

George Washington University

John Logsdon

European Space Agency

Michael Bignier
Gordon Bolton
W. Brado
J.P. Causse
Maurice Delahais
B. Deloffre
J. Dinkespiler
Franco Emiliani
Berndt Feuerbacher
Joachim Graf
Helmut Heusmann
Colin Jones
Karl Knott
Ted Knudson
G. Lafferenderie
Maurice Legg
Norman Longdon
Frank Longhurst
Wilf Mellors
Robert Mory
Wolfgang Nellessen
J. Ortner
B. Pfeiffer
Reg Prescott
G. van Reeth
Chris Reinhold
Rudy Selg
D. Shapland
Frank Sperling
Otto Steinbronn
Heinz Stoewer
Lars Tedeman
Ron Thory
Peter Wolf

ERNO

Wilfried Bark
Jochen Becker
Klaus Berge
Hans Hoffmann
Werner Inden
Ants Kutzer
Jurgen Levold
Jurgen Von Der Lippe
Hans J. Pospiezczyk
Werner Sobotta
Alfred Tegtmeier
Wolfgang Wienss

European Government Representatives

J. Cahen, France
Mario De Leo, Italy
J.L. Flinterman, The Netherlands
Tony Hicks, U.K.
H.L. Jordan, Germany (DFVLR)
Alain Perard, France
Ugo Perticone, Italy
H. Strub, Germany

British Aerospace Corporation

Paul Lathwell
Basil Smith
Ron Staines
Denzil de Villiers

Matra

Jean Baillovoine

Fokker

Robert de Wit

Dornier System

Kurt Gluitz
Peter Lautenbach
Ulrich Picker
Reinhard Shafer
Helmut Ulke

Aeritalia

Roberto Mannu
Paelo Piantella
Ernesto Vallerani
Guisepe Viriglio

APPENDIX

A Memorandum of Understanding

Between The
National Aeronautics And Space Administration
And The
European Space Research Organization
For A Cooperative Programme Concerning Development,
Procurement And Use Of A Space Laboratory In Conjunction
With The Space Shuttle System

PREAMBLE

Pursuant to the offer of the Government of the United States of America to Europe to participate in the major US space programme which follows the Apollo programme, and in particular in the development of a new space transportation system (Space Shuttle), the execution of which has been entrusted by the Government of the United States of America to the National Aeronautics and Space Administration (NASA), European States, members of the European Space Research Organisation (ESRO), have manifested their desire to develop a Space Laboratory, hereinafter referred to as "SL", in the form of a Special Project within ESRO, for the purpose of participation in the Space Shuttle programme. These States, by means of an international Arrangement have charged ESRO or its successor organisation with the execution of the SL programme. In order to provide for appropriate association of the two Agencies in the execution of both programmes and in order to assure the necessary coordination between them, NASA, acting for and on behalf of the Government of the United States of America, and ESRO, acting for and on behalf of the Governments of those States participating in this Special Project, have drawn up this Memorandum of Understanding which sets out the particular terms and conditions under which such association and coordination will be effected. This Memorandum of Understanding will be subject to provisions of the Agreement between the Governments of the above participating States and the Government of the United States of America concerning this cooperative programme.

ARTICLE I

OBJECTIVES

The purpose of this Memorandum of Understanding is to provide for the implementation of a cooperative programme in which ESRO undertakes to design, develop, manufacture and deliver the first flight unit of an SL, and other materials described in this Memorandum. This flight unit will be used as an element to be integrated with the Space Shuttle. This Memorandum sets out furthermore the provisions for ESRO access for use of the SL and for the procurement by NASA of additional SLs, and establishes the cooperative structure between NASA and ESRO for dealing with all questions concerning interface between the Shuttle and SL programmes and concerning the missions to be defined.

ARTICLE II

GENERAL DESCRIPTION OF THE SL PROGRAMME, ITS INTERFACE WITH THE SPACE SHUTTLE, AND ITS USES

1. Summary description of the SL programme

The SL programme provides for the definition, design and development of mannable laboratory modules and unpressurised instrument platforms (pallets) suitable for accommodating instrumentation for conducting research and applications activities on Shuttle sortie missions. The SL module and SL pallet will be transported, either separately or together to and from orbit in the Shuttle payload bay and will be attached to and supported by the Shuttle orbiter throughout the mission. The module will be characterised by a pressurised environment (permitting the crew to work in shirt sleeves), a versatile capability for accommodating laboratory and observatory equipment at minimum cost to users, and rapid access for users. The pallet, supporting telescopes, antennae and other instruments and equipments requiring direct space exposure, will normally be attached to the module with its experiments remotely operated from the module, but can also be attached directly to the Shuttle orbiter and operated from the orbiter cabin or the ground. Both the module and the pallet will assure minimum interference with Shuttle orbiter ground turnaround operations.

2. Interface with Shuttle

The Shuttle will : serve in missions to deliver payloads to earth orbit; maintain station on orbit for mission durations in the order of seven days or more; provide safety monitoring and control over payload elements throughout the missions; and provide seating and complete habitability for crews, including free movement between the SL module and the Shuttle. In the interest of minimising developmental and operational costs, and maximising reliability, an effort will be made to optimise commonality between SL and Shuttle components.

3. Use objectives

The SL will support a wide spectrum of missions for peaceful purposes and will accept readily the addition of special equipment for particular mission requirements. The SL will facilitate maximum user involvement and accessibility. The flight equipment complement will be capable of augmentation as appropriate to satisfy approved programme needs. It will be possible for users to utilise the SL with or without supplementary equipment for a single experiment or, in the alternative, to utilise only a small portion of the SL in combination with other experiments. The standard resources of the SL may be utilised to any degree appropriate by an experimenter adhering to standardized interfaces which are to be defined and procedures which are to be set forth. Considerable flexibility in equipment and mission structuring shall be available to the user for effective mission operation.

ARTICLE III

PHASING AND SCHEDULING

1. Phase B studies

Based on present schedules, the Phase B (preliminary design) studies of the SL are expected to be completed around the end of 1973.

2. Phases C & D

At the completion of the Phase B studies, the parties will mutually agree on a design for immediate implementation and development by ESRO in Phases C & D (final design and hardware development and manufacture).

3. Completion schedules

It is currently planned that the first operational space flight of the Shuttle will occur in late 1979. To permit adequate time for experiment integration, check-out and compatibility testing, the SL flight unit shall be delivered to NASA about one year before the first operational Shuttle flight.

4. Schedule changes

Each party will keep the other fully and currently informed of factors affecting the schedules of the Shuttle and the SL respectively and their potential effects on flight readiness.

ARTICLE IV

PROGRAMME PLANS

The foregoing gross descriptions of the SL programme and of the phasing,scheduling and working arrangements are amplified in greater detail in the preliminary version, dated 30 July 1973, of the Joint Programme Plan. The parties recognise that many issues remain to be resolved in the Joint Programme Plan, which is to be developed and updated as appropriate by the Programme Heads. This plan is to be based on the results of preliminary design studies now in progress in both Europe and the United States, on the results of independent and joint studies of user requirements, and on the final definition of, and the requirements for integration with, the Shuttle.

ARTICLE V

RESPECTIVE RESPONSIBILITIES

1. ESRO responsibilities

Among ESRO's responsibilities are the following :

(a) design, develop and manufacture one SL flight unit (consisting of one set of module and pallet sections), one SL engineering model, two sets of SL ground support equipment, initial SL spares, along with relevant drawings and documentation; and qualify and test for acceptance this equipment according to NASA specifications and requirements;

(b) deliver to NASA the items listed above;

(c) design, develop and manufacture such elements as ESRO and NASA may agree to be necessary for the programme in addition to those listed in (a) above;

(d) establish in the US and accommodate in Europe agreed liaison personnel;

(e) provide all necessary technical interface information;

(f) provide agreed progress and status information;

(g) following delivery of the above flight unit, maintain and fund an SL sustaining engineering capability through the first two SL flight missions, and ensure for NASA's account the future availability to NASA of such engineering capability to meet NASA's operating requirements, on the same conditions as would apply to ESRO;

(h) ensure the production in Europe and possibility of procurement by NASA of subsequent flight units, components and spares; and

(i) provide for preliminary integration of experiments which ESRO supports, as well as acquire the corresponding data, within the overall responsibilities of NASA described in paragraph 2 (j) of this Article, and process it.

2. NASA responsibilities

Among NASA's responsibilities are the following :

(a) establish in Europe and accommodate in the US agreed liaison personnel;

(b) provide general technical and managerial consultation;

(c) provide all necessary technical interface information;

(d) provide agreed progress and status information;

(e) monitor ESRO technical progress in selected areas as defined in the Programme Plans;

(f) review and concur in the implementation of ESRO activities critical to the NASA programmatic requirements for the SL as defined in the Programme Plans;

(g) specify, in order to assure successful operation of the SL in the Shuttle system, operational plans, and hardware and operational interfaces as defined in the Programme Plans;

(h) conduct systems analyses for development of operational concepts and utilisation plans, and assess the impact of changes at all SL external interfaces;

(i) develop selected peripheral components, not part of, but necessary to the successful operation of the SL (e.g. access tunnel, docking ports); and

(j) manage all operational activities subsequent to the delivery of the SL, including experiment integration, crew training, check-out, flight operations, refurbishment, data acquisition, preliminary processing and distribution of data.

3. By agreement of the NASA Administrator and the Director General of ESRO, changes may be made in the above responsibilities, as may be desirable for the implementation of this cooperative programme.

ARTICLE VI

COORDINATION - LIAISON - REVIEWS

1. Programme Heads

Each of the parties has designated in their respective Headquarters an SL Programme Head. They will be responsible for the implementation of this cooperative programme and they will meet and communicate as they require.

2. Project Managers

In addition, each of the parties will designate an SL Project Manager responsible for day-to-day coordination in the implementation of this cooperative programme.

3. Joint SL Working Group (JSLWG)

The two Programme Heads will together establish a Joint SL Working Group with appropriate technical representation from each party. The Programme Heads will be co-chairmen of the JSLWG. The JSLWG will be the principal mechanism for :

(a) the exchange of information necessary to inform both parties fully of the status of both the Shuttle and the SL;

(b) monitoring interface items, problems and solutions;

(c) early identification of issues or problems of either party which may affect the other; and

(d) assuring early action with respect to any problems or requirements.

4. Liaison

The parties shall each provide and accommodate liaison representation at levels as mutually agreed. The representation will be such as to assure each party adequate visibility of the other's progress especially with regard to interfaces and their control. ESRO shall have representation on appropriate Shuttle change control boards to assure adequate opportunity to present the views and interests of ESRO with respect to any change. The ESRO representatives on the boards will have a voice but will not vote. NASA will have similar representation on the comparable ESRO SL board. ESRO and NASA will enable and arrange for visits to their respective contractors as required.

5. Progress reviews

Each party shall schedule progress reviews of its work in the Shuttle and SL programmes and shall provide access to the other to such reviews. Annual reviews will be conducted by the NASA Administrator and the ESRO Director General.

ARTICLE VII

FUNDING

1. Costs

NASA and ESRO will each bear the full costs of discharging their respective responsibilities arising from this cooperative programme, including travel and subsistence of their own personnel and transportation charges for all equipment for which they are responsible.

2. Availability of funds

The commitments by NASA and ESRO to carry out this cooperative programme are subject to their respective funding procedures.

3. Principle on pricing

Neither party will seek to recover government research and development costs incurred in the development of items procured from the other in connection with this cooperative programme.

ARTICLE VIII

NASA PROCUREMENT OF SLs

1. Principle

Subsequent to the delivery by ESRO of the SL unit and other items referred to in Article V,1 (a), NASA agrees to procure from ESRO whatever additional items of this type it may require for programmatic reasons, provided that they are available to the agreed specifications and schedules and at reasonable prices to be agreed. NASA should give an initial procurement order of at least one SL at the latest two years before the delivery of the SL unit referred to above. Recognising the desirability of gaining operational experience with the first flight unit before ordering additional units, but that the price and availability of production units will be dependent on the maintenance of a continuing production capability, NASA will endeavour to provide significant lead time for any subsequent procurement order.

2. NASA abstention from SL development

NASA will refrain from separate and independent development of any SL substantially duplicating the design and capabilities of the first SL unless ESRO fails to produce such SLs, components and spares in accordance with agreed specifications and schedules and at reasonable prices to be agreed. For any NASA SL programme requirements which are not met by SLs developed under this cooperative programme, NASA will have the right to meet such requirements either by making the necessary modifications to the SLs developed under this cooperative programme, or by manufacturing or procuring another SL meeting such NASA requirements.

3. Notice of prospective requirements

NASA will endeavour to give ESRO advance notice of any prospective requirements for substantially modified or entirely new SLs so as to provide ESRO with an opportunity to make proposals which might meet such requirements.

ARTICLE IX

CONTINGENCIES

1. Non-completion of first SL or failure to meet specifications

NASA's obligations with respect to the SL shall lapse and ESRO will turn over to NASA without charge and without delay all drawings, hardware and documentation relating to the SL if ESRO abandons the development of the SL for any reasons, or ESRO is otherwise unable to deliver the SL flight unit prior to the first operational Shuttle flight, or the completed SL does not meet agreed specifications and development schedules. The right of NASA to use the said drawings, hardware and documentation shall be limited to the completion and operation of the SL programme. ESRO shall ensure that it will be in a position to provide as hardware any proprietary item for which it does not hold transmissible rights of reproduction.

2. Non-availability of subsequent SLs

If SLs, components and spares required by NASA after the first flight unit are not available to NASA in accordance with agreed specifications and schedules and at reasonable prices to be agreed, NASA shall be free to produce such units in the United States. For this purpose, ESRO will arrange in advance on a contingency basis any necessary licensing arrangements.

3. Design changes

While it is understood that ESRO will be represented on the Shuttle change control boards, NASA reserves the right to require changes affecting the interfaces or operational interactions between the Shuttle and the SL after hearing and considering ESRO's views with respect to the prospective effect of such changes on the SL design or cost. NASA recognises the desirability of avoiding changes resulting in a disproportionate impact on the SL programme. To the extent that changes affect the Shuttle and SL programmes, NASA and ESRO will bear the increases in the costs of their respective Shuttle and SL development contracts.

ARTICLE X

ACCESS TO TECHNOLOGY AND ASSISTANCE BY NASA

1. Principles

(a) ESRO will have access to technology, including know-how, available to NASA and needed to accomplish successfully its tasks under this cooperative programme; for the same purposes, NASA will have access to technology, including know-how, available to ESRO. NASA will do its best to arrange for such technical assistance as ESRO and its contractors may require for the satisfactory completion of the SL programme. Access to technology and arrangements for technical assistance shall be consistent with applicable US laws and regulations.

(b) NASA will make available to ESRO general information related to the design, development, and use of the Shuttle and orbital system, particularly that required for the understanding of that system.

(c) Requests for use of technology, including know-how, in other than SL development and production tasks will be considered on a case-by-case basis.

(d) To the extent that NASA can make the required information readily available, it will do so without charge; in other cases, NASA will use its best efforts to facilitate its availability on favourable conditions.

(e) The access to technology, including know-how, referred to above will be effected in such a way as not to infringe any existing proprietary rights of any person or body in the United States or Europe.

2. Joint definition of areas

The two parties shall provide for the earliest possible joint definition of areas in which help in the procurement of hardware and technical assistance from US Government Agencies or nationals may be required.

3. Form of assistance

In providing such help to ESRO as may be agreed, NASA may respond on an in-house basis or may refer ESRO and/or its contractors to US contractors. NASA reserves the right to arrange for such assistance in the form of hardware, rather than know-how.

4. Quality control and acceptance

Where ESRO needs to procure US hardware, NASA agrees to use its good offices in connection with arranging the services of US quality control and acceptance and cost control and auditing personnel in US plants where available and appropriate.

5. Facilitation of export licenses

Early advance notification of contemplated ESRO procurements of US hardware or technology, including know-how, will facilitate assistance by NASA in connection with arrangements for export licenses consistent with applicable US laws and regulations.

6. Use of US facilities

Where it is jointly determined that it is appropriate and necessary for the conduct of the cooperative programme, NASA will use its good offices in connection with arranging for the use of US Government or contractors' facilities by ESRO and/or its contractors.

ARTICLE XI

PRINCIPLES CONCERNING ACCESS TO AND USE OF SHUTTLE/SL

1. Planning

There shall be adequate European participation in NASA planning for Shuttle and SL user requirements, with a view to providing for inputs relevant to both the SL design and to European use of the SL. Appropriate representation and relevant procedures are being jointly prepared and will be subject to agreement by NASA and ESRO.

2. Flight crews

Flight crew opportunities will be provided in conjunction with flight projects sponsored by ESRO or by Governments participating in the SL programme and utilising the SL. It is contemplated that there will be a European member of the flight crew of the first SL flight.

3. Special provisions for the use of the first SL flight unit

(a) In order to assure the integrity of operation and management of the Shuttle system, NASA shall have full control over the first SL unit after its delivery, including the right to make final determination as to its use for peaceful purposes.

(b) With regard to the first flight of the first SL unit, the system test objectives will be the responsibility of NASA. The experimental objectives of this first flight will be jointly planned on a cooperative basis. Thereafter, the cooperative use of this first SL unit will be encouraged throughout its useful life although not to the exclusion of cost reimbursable use. NASA will otherwise have unrestricted use of the first SL unit free of cost.

(c) NASA may make any modifications to the first SL which it desires. Should NASA find it desirable to effect major modifications to this unit, these shall be discussed with ESRO which will be given the opportunity to provide modification kits. With respect to minor modifications, the normal procedures for configuration control will be relied on to provide adequate information on changes.

4. Subsequent availability and preferred access to participants

While it is premature to define the ultimate terms and conditions for operation and use of the Shuttle with the SL after the first SL mission, it is expected that the following principles will apply :

(a) NASA will make available the Shuttle for SL missions on either a cooperative (non-cost) or a cost-reimbursable basis. In the latter case, costs which may be charged include, but are not limited to, integration, check-out, crew training and data reduction, processing and distribution, as well as the costs of the launching services provided.

(b) In regard to space missions of ESRO and Governments participating in the SL programme, NASA shall provide access for use of SLs developed under this cooperative programme for experiments or applications proposed for reimbursable flight by ESRO and Governments participating in the SL programme, in preference to those of third countries considering, in recognition of ESRO's participation in this cooperative programme, that this will be equitable in the event of payload limitation or scheduling conflicts. Experiments or applications proposed for cooperative flight will be selected on the basis of merit in accordance with continuing NASA policy; such proposals of ESRO and Governments participating in the SL programme will be given preference over the proposals of third countries provided their merit is at least equal to the merit of the proposals of third countries. ESRO and the Governments participating in the SL programme will have an opportunity to express their views with respect to the judgement of merit regarding their cooperative proposals.

ARTICLE XII

PUBLIC INFORMATION

Each party is free to release public information regarding its own efforts in connection with this cooperative programme. However, it undertakes to coordinate in advance any public information activities which relate to the other party's responsibilities or performance.

ARTICLE XIII

PATENTS AND PROPRIETARY INFORMATION

Each of the parties and their contractors shall retain unaffected all rights which they may have with respect to any patents and/or proprietary information, whether or not they antedate this Memorandum of Understanding. Where it is mutually determined that patentable or proprietary information should be transferred in the interest of successfully implementing this cooperative programme, this may be done under arrangements which fully recognise and protect the rights involved. In addition, each of the parties shall secure from its contractors the rights necessary to discharge the obligations contained in this Memorandum of Understanding in accordance with its internal rules.

ARTICLE XIV

SETTLEMENT OF DISPUTES

1. Any disputes in the interpretation or implementation of the terms of this cooperative programme shall be referred to the NASA Administrator and the Director General of ESRO for settlement.

2. Should the NASA Administrator and the Director General of ESRO be unable to resolve such disputes, they may be submitted to such other form of resolution or arbitration as may be agreed.

ARTICLE XV

DURATION

This Memorandum of Understanding shall remain in force until 1 January 1985, but at least for five years from the date of the first flight of the SL. This Memorandum shall be extended for three years unless either NASA or ESRO gives notice of termination prior to 1 January 1985, or prior to the expiration of the five years, whichever is applicable. Thereafter, the Memorandum of Understanding shall be extended for such further periods as the parties may agree.

ARTICLE XVI

ENTRY INTO FORCE

This Memorandum of Understanding shall enter into force when both the NASA Administrator and the Director General of ESRO have signed it and it has been confirmed under the terms of the Agreement between the Governments of the participating European States and the Government of the United States of America concerning this cooperative programme.

Dated 14 August 1973

For the
European Space
Research Organisation

James C. Fletcher
For the
National Aeronautics and
Space Administration

APPENDIX

B

NASA / ESRO

Joint Programme Plan

For

Spacelab

26 September 1974

Douglas R. Lord
Director, Spacelab Program
National Aeronautics and
Space Administration

Heinz Stoewer
Acting Head of Spacelab
Programme
European Space Research
Organisation

SPACELAB

History of Programme

The Spacelab Programme as a joint US/European venture has evolved during a relatively long period of careful preparation in technical studies and programmatic and political considerations. In January 1969, the United States initiated a high level space planning activity for the post-Apollo period under the U.S. Vice President. Among the recommendations resulting from this activity were those of a reuseable Space Shuttle system between earth and low orbit, a reuseable tug for transferring payloads to and from very high orbits, and a large modular space station to be assembled on orbit. As one very important result of this initial planning activity, Dr. Paine visited Europe in October 1969 to invite European participation in the post-Apollo Programme. A series of conferences on the political level between European and US Government officials took place from 1970 to 1972 and established the general conditions for European participation. During this period, the priorities and scope of the post-Apollo programme had to be modified to be consistent with more restricted U.S. funding. Early development of the Space Shuttle was given priority with the tug delayed for several years and the space station delayed for a longer but undetermined period. In order to provide a capability for conducting space science, applications and technology activities as soon as the Shuttle became operational the revised plan directed attention to sortie missions, i.e. individual flights of the Shuttle lasting between 7 and 30 days. Preliminary studies using the research and applications module concept (the so-called RAM developed for the modular space station) on Shuttle sortie missions were conducted by NASA and supported by European contractors. This was the beginning of the sortie laboratory or Spacelab concept.

The European Space Conference, in consultation with NASA, had funded feasibility studies in several areas of possible European involvement which included the Spacelab concepts. In January 1972, the U.S. President approved NASA's Space Shuttle Programme. In December 1972, the Ministerial meeting of the European Space Conference decided in principle in the context of an overall agreement on future European space projects to accept the U.S. offer of designing, developing and constructing Spacelab. Negotiations which followed led to several international agreements concerning the implementation of this project:

On the European side an "Arrangement between certain Member States of ESRO and ESRO concerning the execution of the Spacelab Programme" was opened for signature in March 1973 establishing the financial envelope for the European part of the programme. Nine European states committed themselves to fund the programme: Belgium, Denmark, France, Germany, Italy, Netherlands, Spain, Switzerland and the United Kingdom.

An intergovernmental agreement between the Governments of these nine European states and the United States "concerning the development, procurement and use of a Space Laboratory in conjunction with the Space Shuttle System" was concluded in August 1973. It identifies NASA and ESRO as the cooperating agencies.

A Memorandum of Understanding dated 14 August 1973 between ESRO and NASA was subsequently signed by the ESRO Director General and the NASA Administrator.

The cooperative programme entered the design and development phase in June 1974, by joint agreement of the NASA Administrator and the ESRO Director General on a design for implementation and development by ESRO.

1. Introduction

This Joint Programme Plan has been drawn up in conformity with Article IV of the Memorandum of Understanding between the National Aeronautics and Space Administration (NASA) and the European Space Research Organisation (ESRO) for a cooperative programme concerning development, procurement and use of a space laboratory (Spacelab) in conjunction with the Space Shuttle system. It amplifies in greater detail the gross descriptions of the Spacelab Programme and of the phasing and scheduling mentioned in Articles II and III of the Memorandum. It also describes in greater detail the working arrangements between NASA and ESRO established in the Memorandum.

The main objective of this document is to provide an overall summary description of the contents and plans for the implementation of the cooperative Spacelab programme. It describes in particular

- the agreed Spacelab concept
- the programme contents
- the working arrangements and management relationships
- the resources.

The Joint Programme Plan covers all phases of the programme established in the Memorandum of Understanding.

According to the Memorandum of Understanding, the programme heads (ESRO Head of Spacelab Programme and the NASA Director of Spacelab Program) will approve, review, and update this document. As an information document it has no controlling authority over the various joint working documents established at the programme management levels.

2. The Shuttle/Spacelab System

2.1 The Space Shuttle Concept

The reuseable Space Shuttle is designed to provide frequent and low cost transportation to and from low earth orbit. The Space Shuttle, which is launched vertically, is a two stage rocket vehicle with a booster stage consisting of two large solid rocket motors recoverable by parachute, and an orbiter vehicle. The orbiter combines the functions of an upper stage with that of a manned orbital spacecraft and a re-entry vehicle.

It lands horizontally after completion of the mission like an aircraft. While all of the high cost elements of the Shuttle system are recoverable and reuseable, the Shuttle also includes a large expendable liquid hydrogen and oxygen tank which provides propellant for the orbiter vehicle.

The Space Shuttle will be able to carry payloads weighing up to 29,000 kg to a 100 n.m. orbit and to return payloads weighing up to 14,500 kg to earth. The Shuttle orbiter will carry the payloads which may have a size of up to 4.5m diameter and 18.3m length in a totally enclosed cargo bay. Accelerations on the payloads will be limited to a maximum of 3 g's. The orbiter will provide the living quarters and provisions for a crew of two or three professional astronauts and up to four payload specialists, who are responsible for conducting the experiments. Shuttle missions will nominally be 7 days in duration but can be extended up to 30 days with reduced payload capacity. On orbit, the orbiter will be capable of supplying payloads with many services including orbit maintenance, stabilisation and pointing, communications, electrical power and heat dissipation.

The Shuttle will operate at first from Kennedy Space Center in Florida and at a later time also from the Western Test Range in California with landing sites nearby. The orbiter will be reuseable approximately 100 times with proper maintenance and refurbishment. An independent tracking and data relay satellite system (TDRSS) will provide nearly continuous communications between earth and the Shuttle and its payloads. The initial orbital flight tests of the Shuttle are planned to begin in 1979.

2.2 Use Objectives

Spacelab capitalises on the low cost transportation to orbit provided by the Space Shuttle and on its unique abilities for frequent access to space and for returning payloads for reuse on subsequent flights. The Spacelab is intended to support a wide spectrum of missions in science and application disciplines by providing simple, economical laboratory and observation facilities. Considerable flexibility in equipment and mission structuring will be available to the user for effective mission operation. It will be possible for users to utilise Spacelab for a single experiment or to utilise small or large portions of the Spacelab in combination with other experiments. Both single-discipline and milti-discipline missions are envisaged in the following fields: solar astronomy, infrared astronomy, high energy astrophysics, atmospheric and plasma physics, life sciences and space biology, earth observations, communication and navigation, material science and manufacturing in space, space technology. Additional areas that might gain from using Spacelab will probably be recognised as the programme matures.

Important objectives of the Spacelab Programme are to reduce significantly the time from experiment approval to the availability of results and to reduce the costs significantly of space research and applications compared with any current techniques. Direct space research will be possible for qualified experimenters, men and women, without unusual physical fitness requirements or rigorous and lengthy astronaut training.

The Spacelab plans to maximise its research effectiveness by involving the users throughout all mission phases and by permitting users to employ their own ground laboratory type equipment in space where feasible.

2.3 The Spacelab Concept

2.3.1 General

To meet the broad range of mission objectives, the Spacelab system has been configured to provide pressurised compartments (modules) and unpressurised equipment mounting platforms (pallets). Moreover, the Spacelab system includes supporting subsystems, mission dependent support equipment, ground support equipment and Shuttle interface equipment.

Transport of Spacelab to and from orbit and its operational support on orbit will be provided by the Space Shuttle system. Spacelab remains in the Shuttle orbiter cargo bay during the whole flight. Modules and pallets can be flown separately or in various combinations, depending on mission requirements. Three baseline configurations have been identified : the long module, the short module plus pallet and the pallet-only.

The Spacelab crew consists of one to four payload specialists who work in Spacelab but have their accommodation quarters throughout the mission in the orbiter cabin where they will also stay during launch,re-entry and landing.

Complete experiment integration at the home site of a user organisation will be possible and for this purpose the experiment equipment and mounting elements (racks and pallets) are of such dimensions that they can be shipped in a C5A aircraft.

2.3.2 Programme Requirements

Several fundamental programme requirements impacted on the evolution of the programme concept and the definition and design of system and subsystem hardware. Limited by the orbiter landing capability of 14 500 kg (32,000 LB) the total Spacelab design weight is established to allow between 15 and 23% weight margin as a programme reserve for both payload and Spacelab growth. Unmargined weights available for payloads (primarily experiment equipment and facilities) will be between 5500 kg and 9100 kg on all 7-day missions. The centre of gravity limits of the Shuttle system require the placing of the Spacelab in the rear portion of the orbiter payload bay and the utilisation of a crew transfer tunnel of variable length between the orbiter and the pressurised module. The Spacelab flight units will be capable of at least 50 seven-day missions or ten years of operation with suitable ground maintenance and refurbishment.

Requirements for low operational and development cost will lead to the use of commercial avionics and military equipment where applicable and the adoption of other low cost techniques such as minimal testing, large design factors, and reuseability.

2.3.3 The Pressurised Module

The basic short module contains a core of subsystem equipment and provides for several cubic metres of rack-installed experiment equipment. An extension module section is dedicated entirely to experiment installation. The long module configuration comprises the basic and the extension module sections. Both module sections are of the same length of approximately 2.7 metres. The subsystem and experiment equipment are housed in standard racks independently attached to the floor. The racks and associated floor segments can be removed during ground operations. Power, signal and fluid lines are carried beneath the floor. Large airlocks that may be used for experiments may be installed at the top of the basic module section and in the aft module bulkhead. The end cones of the pressurised module also provide crew access, utility feedthrough and viewpoints as necessary.

2.3.4 The Pallet

The instrument mounting platform or pallet is located aft of the pressurised module. Telescopes, antennas and other instruments which need direct exposure to space or which require wide viewing angles are mounted on the pallet and can be operated remotely from the module, the orbiter cabin or by command link from the ground. The pallet is composed of one to five pallet segments each of approximately 3 m in length. They are attached to the orbiter by separate fittings and are detached from the pressurised module. The module and the pallets are interconnected by a utility bridge carrying any subsystem and experiment support functions. In the pallet-only mode the orbiter-to-pallet interface is provided by a pressurised support unit which is thermally controlled and which contains subsystem elements needed for the pallet.

2.3.5 Ground Support Equipment

The electrical ground support equipment consists of an orbiter interface adapter, experiment/subsystens simulators, ground power supply, a computer, other peripherals and special calibration and test equipment. The mechanical ground support equipment includes containers for safe transportation, work stands, storage fixtures and contamination protection. A mechanical Spacelab simulator is provided for fit-checks with the orbiter and facilities.

2.3.6 Orbiter interface

Prime consideration in designing Spacelab are to minimise interface complexity with the Space Shuttle orbiter and provide maximum resources for the user without exceeding funding limits. The result is a mix of autonomous and orbiter dependent subsystems. Spacelab depends on the orbiter for its primary electrical power and for most of the heat rejection. The basic stabilisation and control are provided by the orbiter. Also the orbiter is responsible for normal communications with the ground, rescue operations and equipment, maintenance of the desired orbit and provision of Spacelab crew accommodations. However, an autonomous computer capability was retained for Spacelab and the air revitalisation subsystem can operate independently of the orbiter. The mechanical orbiter/Spacelab interface includes the attachment points in the payload bay, a tunnel on the Spacelab side and an operational airlock on the orbiter cabin side.

2.3.7 Subsystems

The structural subsystem is composed of the module pressure vessel, the unpressurised pallet structure and the module internal secondary structure, which supports the subsystem and experiment equipment. The two identical cylindrical shells are interchangeable and enclosed by end cones. The module floor provides access to those subsystem elements stored beneath it. Bolted joints with seals are used to join the end cones to the cylinder sections and the cylinders to each other. Elsewhere the primary structure is welded. The outer skin of aluminum alloy employs an integrally machined waffle pattern on the inside. The pallets are structurally linked together or may be individually attached to the orbiter.

The primary electrical power is derived from a dedicated orbiter fuel cell and Spacelab's electrical power and distribution subsystem (EPDS) provides conditioning and distribution to the subsystems and payloads.

The environmental control subsystem (ECS) encompasses elements for environmental control, life support and passive and active thermal control. Active thermal control is effected by a two-fluid-system of water within the module and freon on the pallet conveying the heat loads via heat exchangers to the orbiter for heat rejection. Within the module cooling is mainly by air circulation but provision is made in the module for cold plates if required.

For the command and data management subsystem (CDMS) three identical computers are envisaged, one each for subsystems and payload and one for redundancy. Controls and displays in the basic module are duplicated in the payload specialist station of the orbiter. On-board recorders are available as required. The CDMS provides data for communication to the ground and receives and distributes commands via the orbiter. Limited on-board data processing will be possible utilising software supplied by the experimenter.

Common payload support equipment will be provided which may be used by more than one experiment or other payload activity. This equipment includes: scientific airlocks, viewports, optical windows, feedthroughs, venting provisions, and a film vault.

An instrument pointing subsystems will be available for use with pallet-mounted equipment which requires a high degree of pointing accuracy.

2.3.8 Payload Capabilities

The following weights will be available for experiment hardware and experiment related equipment and services at the discretion of the user, based on 7-day missions:

Configuration	Payload
Long module	5500 Kg
Short module and 6-9 m pallet	5500 Kg
Pallet-only 9 m	9100 Kg
Pallet-only 15 m	8000 Kg

2.3.9 Supplementary Equipment

A variable length crew transfer tunnel will connect the orbiter cabin with the pressurised module. An inside clear diameter of approximately 1 meter will be provided. A section of the tunnel will contain provisions for extravehicular activity by astronauts in pressure suits.

Shuttle interface verification equipment will provide the electrical, mechanical and fluid Shuttle/Spacelab interface for testing purposes.

The software test integration laboratory will provide the capability required to support the integration, verification, and maintenance of software for GSE, Spacelab subsystems and experiment support.

2.4 The Spacelab Flight Concept

2.4.1 Preparation of Experiments and Experimenters

While many aspects of the Spacelab operational concept have not yet been established, the following description is believed to be representative. The unique preparations for a given Spacelab flight will be conducted at one or more user locations such as a university, a government laboratory, or an industrial research centre or at various NASA or ESRO centres serving as Spacelab integration facilities. Here the payload equipment will be installed in standard racks or mounted on pallet segments and the support service connections, data transmission lines, controls, and computer programmes checked out. The payload specialists on a particular flight who may come from the user organisations, will receive several months of special training and familiarisation with the Shuttle and Spacelab in addition to intensive training on the experiment equipment. Following installation and integration of the experiments in the racks and on the pallet segments, these units will be shipped to the launch site for incorporation into the total Spacelab system. Shipment will normally be by aircraft.

2.4.2 Preparation of Spacelab

Concurrent with the payload activities, a Spacelab basic module containing the subsystems will be refurbished from a previous flight in preparation for the next. Spacelab may consist of both a pressurised module for manned research operations and/or a pallet for mounting viewing instruments. Final integration will consist of mating the basic module to extension modules and to the pallet which contain the experiments. The assembled units will then be installed in the orbiter payload bay, subjected to final checkout, and transferred to the launch pad. Final access to payloads such as biological specimens will be possible on the pad up to a few hours before launch.

2.4.3 Spacelab Launch

The Spacelab will be transported into low earth orbit in the closed payload bay of the Space Shuttle orbiter. During this portion of the flight, Spacelab will be essentially inactive and the entire Shuttle crew including the commander, the pilot, the mission specialist and all of the payload specialists will be seated in the orbiter cabin.

2.4.4 On-Orbit Activities

After reaching orbit, the orbiter payload bay doors will open to expose the radiators and the Spacelab windows and instruments. Spacelab activation will be conducted from the orbiter cabin, primarily by the three professional astronauts. The payload specialists will then enter the pressurised module through an access tunnel and set up and conduct their experiment operations in a comfortable sea level pressure, oxygen/nitrogen atmosphere. The experiments mounted on the pallet will normally be controlled from within the module. In the pallet-only configuration, the experiments will be controlled either from the payload specialist station on the orbiter flight deck or from the ground via a radio link. Single or multiple shift crew operations will be possible so that Spacelab may be operated 24 hours a day. Manned operations in pressure suits outside the orbiter cabin and Spacelab module (EVA, extravehicular activity) required for experiment operations or maintenance and repair will be conducted using the orbiter personnel airlock and a hatch attached to the crew transfer tunnel. It is expected that experiment operations will continue in the Spacelab module while EVA activity is in progress.

While in orbit the payload specialists will be able to consult with their colleagues on the ground by nearly continuous communications through a tracking and data relay satellite system. The same system will make it possible to transmit television pictures and wide band data to earth for assessment by scientists and engineers at the user's home laboratory.

2.4.5 Flight Termination

After completion of the flight objectives the Spacelab crew will stow their equipment and return to the orbiter cabin for the de-orbit and re-entry phase. The Spacelab will be deactivated and returned to earth in the closed payload bay. Normally the acceleration level during orbiter re-entry will not exceed 2 g's.

The orbiter will land like an airplane on a runway close to the launch site. Following an appropriate cool down period and safing procedures, the Spacelab will be removed from the orbiter and the payload elements removed from the Spacelab and returned to the user's home site. Refurbishment procedures will then be carried out on the basic Spacelab elements at the launch site followed by reconfiguration for the next flight as required. Data tapes, photographs, specimens and other experimental results will be returned to the user installations for data processing and analysis.

3. The Spacelab Programme

3.1 Summary Description of Spacelab Programme

3.1.1 General

The Spacelab Programme includes the definition, design, development and manufacture of pressurised modules, pallets, ground support equipment payload support equipment, interface equipment and associated software. The programme also includes planning for ground operations, involving experiment integration, check-out, test and maintenance and planning for flight operations including mission control, crew training and data management. The end products of the programme will include one Spacelab flight unit (for NASA), two engineering modules (one for NASA, one for ESRO), three sets of ground support equipment (GSE, two for NASA, one for ESRO) and initial spares and documentation.

3.1.2 ESRO Responsibilities

ESRO is responsible for the design and development of the Spacelab concept agreed to jointly by NASA/ESRO at the start of the design and development phase. ESRO will direct the manufacture, qualification, acceptance test and delivery to the U.S. of one Spacelab flight unit, one engineering model, two sets of Spacelab GSE, initial spares,and documentation, and will also provide sustaining engineering through the first two Spacelab flights and ensure the future availability to NASA of such engineering capability to meet operating requirements on the same conditions as would apply to ESRO. ESRO will also ensure the production in Europe and possibility of procurement by NASA of subsequent flight units, components and spares. ESRO will further be responsible for preliminary integration of ESRO supported experiments.

3.1.3 NASA Responsibilities

NASA has primary responsibility for all operational activities subsequent to the delivery of Spacelab, including experiment integration, crew training, check-out, flight operations, refurbishment, data acquisition, preliminary processing and distribution of data.

NASA is also responsible for the design and development of selected peripheral components such as the crew transfer tunnel, Shuttle interface verification equipment, and Spacelab crew training equipment.

3.2 Programme Milestones

The principal programme milestones consist of a series of incremental formal programme reviews, hardware deliveries, and initial flights. The series of reviews will start in late 1974 and will be conducted at selected points in the development programme.

In order to establish a conceptual baseline for subsequent project reviews, a Preliminary Requirements Review (PRR) will be held in late 1974. The prime purpose of the PRR will be to review system requirements, and to give preliminary formal approval to higher level system specifications and plans, and determine requirements and actions necessary to achieve a design baseline at subsequent reviews.

A System Requirements Review (SRR) will take place in early 1975. The purpose will be to update system requirements, and to ensure compliance of lower level documentation with the system requirements.

The baseline established by the SRR serves as the start for the final subsystem definition and design phase during which detailed designs will be developed, interfaces will be finalised, manufacturing drawings will be prepared and test procedures will be developed.

The Preliminary Design Review (PDR) to be held in the fall of 1975 is intended as a technical review of the basic design approaches for the Spacelab equipment to assure compatibility with the technical requirements including interface requirements and the producibility of the design approach. This review will update the baseline requirements and will place interface control documentation under configuration control.

The PDR will result in the authorisation to the contractor to proceed with the Engineering Model design and manufacture in accordance with the reviewed baseline.

The Critical Design Review (CDR) will take place at the end of the design and development phase late 1977 and will formally establish the production baseline for the first flight unit.

The purpose of the CDR will be to determine the compliance of the complete design as demonstrated by the Spacelab engineering model tests, with the design requirements.

The engineering model (module and pallet) and one set of GSE will be completed and delivered to NASA one year prior to the delivery of the first flight unit.

The crew transfer tunnel will be completed by NASA and delivered to ESRO in mid-1977 to support the engineering model integration test.

It is currently planned that the first operational space flight of the Space Shuttle will occur in 1980 and that the first Spacelab unit will fly on-board the first operational Shuttle flight. To permit adequate time for experiment integration, check-out and compatibility testing, the Spacelab flight unit shall be delivered to NASA about one year before the first operational Shuttle flight.

3.3 Programme Implementation

Technical planning for the Spacelab Programme is divided into four basic phases:

(1) Feasibility study phase A

(2) Definition study phase B

(3) Design, development and manufacturing phase C/D

(4) Operational phase

3.3.1 Feasibility Study Phase A

Feasibility studies were conducted by both NASA and ESRO in 1972. The NASA studies were carried out by an in-house team at the Marshall Space Flight Center. ESRO contracted for three Phase A studies from June to November 1972 with the COSMOS, MESH and STAR consortia led by Messerschmitt-Bölkow-Blohm (MBB), VFW-Fokker/ERNO and British Aircraft Corporation (BAC) respectively.

The studies had three major objectives: preliminary requirements determination, initial trade-off studies, and candidate concept definition.

ERNO chose a modular concept in which both the module and the pallet are in modular form. MBB's preferred concept was its "Common Support System/Integrated Payload System (CSS/IPS)", comprising a basic shell and a removable payload system. BAC concentrated principally on the "General Purpose Lab" concept.

The studies showed that the Spacelab was a viable concept for support of Shuttle sortie missions in an earth orbital science, applications and technology programme.

3.3.2 Definition Study Phase B

Parallel project definition activities were conducted by Marshall Space Flight Center (MSFC) for NASA and by two European industrial teams for ESRO. ERNO and MBB led the industrial teams. The NASA studies were terminated in September 1973 after the Memorandum of Understanding was signed. The ESRO studies were completed in May 1974.

The primary objectives of the definition studies were in their early phase to provide a data base for the programme commitment and the final go-ahead in July 1973, and later to optimise the concept and to advance it to a level of detail compatible with commencement of the design, development and manufacturing phase.

The studies showed that ESRO responsibilities within the Spacelab Programme can be performed within the overall ESRO financial constraints. The ERNO and MBB teams carried out preliminary design, programme planning and detailed cost analyses on two concepts, a modular concept (ERNO) and a cargo aircraft concept (MBB). Both concepts proposed by the industrial teams accepted the principles of modularisation and removable secondary structure.

During the phase B studies several important programme decisions were taken, including the establishment of a firm Spacelab diameter and payload weight design goals. Subsystem support resources available to Spacelab from the orbiter were identified.

In March 1974 ESRO issued to ERNO and MBB a request for proposals for the total work during the design, development and initial operations phase of the Spacelab Programme. Both proposals were based on the results of the phase B studies and prepared by the same teams which were involved in the definition studies. The evaluation of the proposals by ESRO led to the selection of the ERNO proposal.

3.3.3 Design, Development and Manufacturing Phase C/D

In June 1974 phase C/D began. Under an ESRO contract awarded to the VFW-Fokker/ERNO team the prime contractor is responsible for the delivery of hardware, documentation and software. In addition to the items committed by ESRO to NASA under the terms of the Memorandum of Understanding the contractor will deliver to ESRO certain hardware and software items.

End items of the phase C/D will include:

- one flight unit to be delivered to NASA in April 1979.
- two engineering models for the development of maintenance and refurbishment procedures, experiment integration verification, crew training and mission simulation to be delivered in April 1978 to NASA, and January 1979 to ESRO.
- one hard mock-up for configurational studies, to be delivered to ESRO in April 1979.
- mission dependent support equipment such as airlocks and one instrument pointing system to be flown on selected missions as required to be delivered to NASA.
- electrical and mechanical equipment simulating the Spacelab characteristics for Spacelab/Shuttle and Spacelab/payload interference tests.
- electrical ground support equipment for transportation and system and subsystems check-out during Spacelab integration and testing.
- mechanical ground support equipment for Spacelab integration, ground handling, transportation, storage, and servicing for fluid systems.
- software (programmes for performance check-out, control during flight phases, etc.).

During the phase C/D the specific design and programme plans for manufacturing, testing, operations, management and procurement will be further developed and implemented by the contractor for use by ESRO/NASA.

3.4 The First Spacelab Flight

The first Spacelab mission will have two primary objectives :

- verification of the principal Spacelab design aspects and capabilities.
- successful accomplishment of significant scientific, applications and technology objectives.

The system test objectives are the responsibility of NASA. The experimental objectives are jointly planned by NASA and ESRO. It is contemplated that there will be a European member of the flight crew on the first Spacelab flight.

Present plans indicate that the first flight will use a large module and small pallet combination and shall last not longer than seven days.

The flight will be launched from the Kennedy Space Center Cape Canaveral, Florida.

In order to prove the Spacelab performance, to confirm its operability and to measure its induced environment, special verification flight instrumentation will be installed. Several verification flights may be required in view of the number of different Spacelab configurations which can be assembled. The special instrumentation will be removed after verification is completed.

The experiment payloads for the first flight will be selected with the intent of demonstrating to the user community and the general public the uniqueness of Spacelab and its broad capability for research, applications and technology.

3.5 Supporting Activities

In addition to the Spacelab Programme effort outlined above, NASA and ESRO are currently conducting activities which support the programme and the results of which will flow into the programme.

3.5.1 NASA Supporting Activities

The following areas will be covered:

- Ground Operations - Studies will be conducted to determine methods of refurbishment, experiment installation, check-out and ground processing of major Spacelab elements and of the spares inventory and transportation support required.
- Flight Operations - Plans will be developed for real time mission planning, crew timelines, in-flight procedures, data management, and training procedures for flight crews.
- Experiment Definition - Numerous studies are being conducted in many different scientific, applications and technology disciplines to define specific experiments to be conducted on Spacelab in the 1980's.
- Payload Accommodations - These studies evaluate Spacelab payload accommodations and will lead to the development of experiment integration procedures.
- Contamination Control - This activity will support the programme using knowledge gained in Skylab and other space programmes. NASA will define contamination sources, identify equipment/experiments sensitive to contamination and develop control procedures to minimise contamination.

- Concept Verification Testing (CVT) - This ground-based activity simulates experiment integration and operating techniques. In this way operational planning and concepts and potential interface problems can be examined in premission ground operations.

- Airborne Science Shuttle Experiment System Simulation (ASSESS) - This project also examines experiment operations techniques. It utilises NASA's Airborne Science Programme to determine experimental techniques, management concepts, and operating procedures best suited for the Spacelab Programme. Spacelab experiment hardware will be flown in aircraft to simulate flight conditions and provide insight into user-experiment systems capabilities and limitations.

- Miscellaneous Studies - NASA is conducting studies to determine operational hazards associated with projected missions. Studies are also being conducted to determine software interface test procedures and the facilities required to perform this function. Materials properties and compatibility are also being studied in support of the total programme.

3.5.2 ESRO Supporting Activities

There are three important technical areas that require further effort to ensure efficient use of the Spacelab system. These are (1) experiment evaluation; (2) mission analysis; and (3) supporting technology.

ESRO has initiated studies of experiments that might be flown in Spacelab and has identified typical payloads that are representative of the various disciplines. The studies have helped to establish requirements for Spacelab design as well as to identify in a preliminary fashion typical experiment hardware. In support of these general activities ESRO is evaluating what can be learned from the conversion of experiments originally conceived for automatic spacecraft, balloons and aircraft to ones that could operate in Spacelab. These studies are grouped under the heading of Spacelab Experiment Support Studies (SLESS). Additional evaluation of experiment procedures and Spacelab subsystem interactions is being performed through support of three European experiments to be flown on a joint ESRO-NASA ASSESS Mission. Finally in this area ESRO is developing a set of procedures for selecting and developing European experiments that will be flown in Spacelab.

In keeping with established ESRO-user community relationships a number of mission groups have been formed or are being formed to evaluate Spacelab mission applications. Experiment definition and accommodation analyses will be carried out in support of these activities.

In the area of Spacelab development itself, various technology studies and development efforts are required immediately to verify critical technology areas.

4. Working Arrangements and Management Relationships

4.1 ESRO/NASA Programme Coordination

4.1.1 General

Spacelab is a cooperative international programme. The management and organisational arrangements reflect this close relationship and provide Europe to U.S. symmetry wherever appropriate. In view of the size of the programme, and in order to keep the programme viable for its entire duration, the arrangements must provide procedures to arrive at mutual agreement and joint decisions without compromising the technical scope of the programme.

In carrying out their respective programme responsibilities, NASA and ESRO schedule progress reviews of their respective work in the Space Shuttle and Spacelab Programme and provide access for each other to such reviews.

ESRO and NASA enable and arrange for visits to their respective contractors as required.

As a cooperative management tool, control rooms with duplicate Spacelab management control information are being established, at ESRO and NASA Headquarters, ESTEC and MSFC.

4.1.2 Agency Heads

The NASA Administrator and the ESRO Director General are supervising the execution of the Spacelab Programme on their respective sides. Joint annual programme reviews are conducted by them. They are called to settle disputes, should any arise, in the interpretation or implementation of the terms of the programme. They are entitled to change, by mutual consent, the responsibilities of ESRO and NASA as delineated in the Memorandum of Understanding.

4.1.3 Programme Heads

NASA and ESRO have each designated in their Headquarters a programme head. They represent the main point of contact between the two agencies with regard to the Spacelab Programme, and are responsible for the implementation of the programme. They establish and update the Joint Programme Plan, the Level I Programme Requirements document and the level I programme directives. They meet and communicate as required.

4.1.4 Joint Spacelab Working Group (JSLWG)

The two programme heads serve as co-chairman of a Joint Spacelab Working Group with appropriate representation from each side. The JSLWG is the principal mechanism for:

- the exchange of information necessary to inform both sides fully of the status of both the Space Shuttle and the Spacelab development programmes.
- monitoring interface items, problems and solutions.
- early identification of issues or problems on either side which may affect the other.
- assuring early action with respect to any problems or requirements.

The programme heads may establish ad hoc task groups for implementation of the mandate given to the Joint Spacelab Working Group. The Working Group meets at the call of the programme heads alternatively in Europe and the United States. Agenda items are proposed and agreed by the programme heads. After resolution of the items, actions are implemented by the respective Agencies.

4.1.5 Project Managers

For the day to day coordination of the programme, NASA and ESRO have each appointed a project manager, located with his respective team, at Marshall Space Flight Center (MSFC), Huntsville, Alabama, and ESRO's European Space Research and Technology Centre (ESTEC), Noordwijk, the Netherlands. Direct contact occurs between these two managers. They maintain frequent direct contact with each other and are jointly responsible for issuing and updating the necessary system requirements and interface documents at level II.

4.1.6 Liaison

NASA and ESRO provide and accommodate liaison representation such as to assure each party adequate visibility of the other's progress, especially with regard to interfaces and their control. ESRO representatives are stationed at NASA Marshall Space Flight Center, Huntsville, Alabama and Johnson Space Center, Houston, Texas. Similarly, NASA representatives are stationed at ESTEC in the Netherlands. ESRO has representation on Level I and Level II Shuttle Program Requirements Change Boards. NASA will have similar representation on the comparable ESRO Spacelab Board, when established.

4.1.7 Payload Planning Groups

For the purpose of arriving at the requirements of potential users for the design of Spacelab, NASA and ESRO have established a Joint User Requirements Group (JURG). The NASA/ESRO co-chairmen of JURG are members of the Joint Spacelab Working Group, in order to ensure the incorporation of the user requirements into the design effort as well as the users' comments on the Spacelab design concept as it evolves.

A joint NASA/ESRO Planning Group has been established for the coordination of soliciting and selecting experimental objectives for the first Spacelab payload.

ESRO and NASA are conducting studies to define further Spacelab payloads. Some of the missions covered by these studies are candidates for future NASA/ESRO cooperative projects. In these cases NASA has invited ESRO participation in the NASA Scientific Groups concerned and vice versa. In addition, there are two ESRO representatives on the NASA Shuttle Payload Planning Steering Group.

NASA and ESRO have also formed a Joint ASSESS Mission Planning Group for the planning of a cooperative CV-990 Spacelab Simulation Mission in 1975.

4.2 ESRO Spacelab Organisational Structure

Spacelab has been accepted by the ESRO Council as a "special project". An ESRO "special project" is one in which the participation of all ten Member States (*) is not mandatory, and for which ESRO assistance and facilities are made available.

The costs of the European part of the Spacelab Programme are met through special payments to ESRO by the participating states (**). The programme and annual budget decisions are taken by the Spacelab Programme Board, composed of representatives of the participating states. For matters affecting more than the Spacelab Programme, the Programme Board advises the ESRO Council. Spacelab contractual decisions are delegated by the Council to the Administrative and Finance Committee (AFC), in which all Member States are represented.

The Head of the Spacelab Programme at ESRO Headquarters is responsible within ESRO for general management and the implementation of this cooperative programme. He reports directly to the Director General of ESRO. The responsibilities of ESRO Headquarters include budget, programme integration and relations with the Spacelab Programme Board.

The Spacelab project team is located at ESTEC. The managers of the systems, the module, operations, project coordination and control, and product assurance and safety divisions report to the Project

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(*) ESRO's Member States are Belgium, Denmark, France, Italy, Netherlands, Spain, Sweden, Switzerland, United Kingdom, West Germany.

(**) All ESRO Member states except Sweden are participating states. Percentage contributions deviate from those of regular ESRO projects for which the contributions are made by Member States in proportion to their GNP.

Manager. All industrial work is coordinated and supervised by the project team.

The Director of ESTEC is responsible for technical and administrative support of the project team at ESTEC.

4.3 NASA Spacelab Organisational Structure

The NASA Associate Administrator for Manned Space Flight (MSF) has overall responsibility within NASA for the Spacelab Programme. Responsibility is exercised through the Director, Spacelab Program, who is charged with overall programme planning, direction, and evaluation, including recommending the NASA programme budget and allocating and controlling NASA programme resources within authorised levels. Implementation of these responsibilities is through the Spacelab Program Manager at Marshall Space Flight Center (MSFC).

The Director, Spacelab Program, is responsible within NASA for level I program requirements, including performance, major milestones, schedules, configuration and program interfaces. He is assisted in these tasks by a small staff organised into the engineering and operations; experiment accommodations; program budget and control; reliability, quality and safety; and CVT project directorates.

The Spacelab Program Manager at MSFC is responsible for determination of systems requirements and specifications, level II Spacelab interfaces, planning experiment integration and operations concepts, and preparation of all NASA center funding requirements in support of the Spacelab Programme. He is assisted by a staff divided into the operations, experiment integration, programme engineering and integration, and development and management projects, and the programme control office.

The Space Shuttle Program Director, and the Space Shuttle Program Manager, Johnson Space Center (JSC) are responsible for supporting the Spacelab Programme by establishing and controlling Shuttle Orbiter level I and level II system interfaces and overall safety requirements for Spacelab.

The Launch Site Spacelab Manager, Kennedy Space Center (KSC) in Florida is responsible for supporting the Spacelab Programme by defining and developing launch site preparation and launch site logistics concepts for both the Eastern Test Range (ETR) and the Western Test Range (WTR) in California. He is also responsible for defining Spacelab pre-launch and postlanding operations.

4.4 Contractor Spacelab Organisation Structure

ESRO has selected a European industrial team for the design and development phase of the Spacelab Programme. The prime contractor is VFW-Fokker/ERNO (Germany) with responsibilities assigned to the following co-contractors:

Aeritalia (Italy)	Module structure, thermal control
Bell Telephone Manufacturing (Belgium)	Electrical ground support equipment
Engins Matra (France)	Command and data Management
Inta (Spain)	Mechanical ground support equipment
AEG Telefunken (Germany)	Electrical power distribution
Fokker-VFW (Netherlands)	Airlocks
Dornier System (Germany)	Environmental control, instrument pointing system
SABCA (Belgium)	Utility bridge
Hawker Siddeley Dynamics (United Kingdom)	Pallet structure
Kampsax (Denmark)	Computer software

The work distribution generally follows the pattern of the financial contributions to the programme by the various participating ESRO Member States.

The VFW-Fokker/ERNO team will be responsible, with ESRO's guidance, for the management of the design and development, systems engineering, product assurance, test and manufacture of the hardware and software items including documentation required to fulfill ESRO's programme obligations.

4.5 Configuration Management and Interface Control

Configuration control is enforced at the various management levels. The Level I programmatic requirements and changes thereto are the responsibility of the Joint Spacelab Working Group. The Level II requirements and changes thereto are the responsibility of the Joint NASA/ESRO Level II Programme Requirements Control Board (PRCB).

For all other levels, ESRO has a configuration control procedure with its contractors, to which NASA has observer status. Similarly NASA has configuration control procedures with its contractors.

The interfaces between Spacelab and the Shuttle orbiter, the crew transfer tunnel, the facilities and the payloads, are jointly controlled as follows :

Spacelab-orbiter interface: control documents are established by the Spacelab and Shuttle programme managers.

Spacelab-tunnel interface: control is assigned to the Spacelab prime contractor with such items involving level II being brought to the project managers for joint decision.

Spacelab-facilities interface: the builders of the facilities are continually informed of the status and configuration of Spacelab to enable their planning. When interfaces are identified, they will be jointly signed and controlled by the Spacelab and the facilities programme managers.

Spacelab-payloads interface: a Spacelab payload accommodations handbook is being established and will be issued to potential Spacelab users. This handbook contains all relevant information on resources for users.

4.6 Programme Documentation

The NASA and ESRO programme heads have identified programme areas which require mutual involvement to insure successful accomplishment of the Spacelab mission. Responsibilities for originating and controlling the documents associated with these areas have been assigned and generally reflect those described in the Memorandum of Understanding.

Since ESRO is responsible for the major Spacelab flight and ground support hardware and system software, ESRO is also responsible for initiating and controlling the documents which define system requirements and design and development plans. Since NASA is responsible for the overall space transportation system and for Spacelab operation, payload integration, crew aspects, and safety, NASA is also responsible for initiating and controlling the documents which define programme requirements, user policies, operations plans, and external system interfaces.

A description of the major top level programme documents is given below. Because of the cooperative nature of the programme, joint signatures are required on many of the documents. The individual document responsibilities are given in the Programme Requirements document level I.

Memorandum of Understanding (MOU)

This document sets forth the basic agreements between NASA and ESRO on the major cooperative aspects of the Spacelab Programme. It gives the objectives and general description of the programme and assigns programme responsibilities. It describes principles of funding, NASA procurement and contingencies.

The document was jointly signed in September 1973 by the Director General of ESRO and the Administrator of NASA. It remains in effect until five years after the first flight of the Spacelab at least until 1985.

Joint Programme Plan (JPP)

The JPP is a jointly signed level I document which amplifies the gross programme descriptions given in the MOU. It is a non-controlling document for informational purposes.

Programme Requirements Document (PRD)

This document establishes the level I programme requirements for the Spacelab Programme. It consists of two parts. The first part relates to overall system requirements (subsystem characteristics, operational constraints, interface requirements, etc.). The second part is concerned with programme implementation requirements. The document is jointly signed by the NASA and ESRO programme heads.

Users Guide

The Spacelab payload will consist of experiments which will be selected from a large community of potential suppliers. The system constraints to which the user must comply are described in the Users Guide. It also sets forth the process by which experiments are proposed for use on Spacelab and the manner in which selection is made. The guide is for informational purposes and is jointly signed by ESRO and NASA programme heads.

Programme Directives

Direction on major activities may be issued when appropriate by the programme heads individually or jointly in the form of programme directives.

5. Resources

5.1 ESRO Resources

According to the 'Arrangement between certain Member States of ESRO and ESRO concerning the execution of the Spacelab Programme', the financial envelope of the programme at the date of opening the Arrangement for signature (15 March 1973) was estimated at 308 Million Accounting Units (*) at mid-1973 prices. One Accounting Unit at present corresponds to 1.26 U.S. dollars. This figure is broken down in the Arrangement as follows:

	MAU
Phase B studies	10.0
Main development contract	175.0
ESRO internal expenditures	63.0
Space technology	15.0
Contingency, including Shuttle Programme modification not covered by main development contract	45.0
	308.0

The following European states have guaranteed to pay contributions to the Spacelab Programme at the percentages indicated (**):

Belgium	4.2 %	Netherlands	2.1 %
Denmark	1.5 %	Spain	2.8 %
France	10.0 %	Switzerland	1.0 %
Germany	54.1 %	United Kingdom	6.3 %
Italy	18.0 %		
			100 %

In the event of a change in price levels, the financial envelope of the programme will be revised in conformity with an ESRO procedure which takes into account any price changes which occur in all ESRO Member States. The provisional update of the financial envelope to mid-1974 price resulted in an upward revision to 336 Million Accounting Units.

In the case of cost overruns other than those caused by change in price levels, and if cumulative overruns of estimated cost to completion do not exceed 20 % of the amount of the financial envelope of the programme, no participant shall be entitled to withdraw from the programme in accordance with the 'Agreement' and the Programme Board shall decide on the additional expenditure.

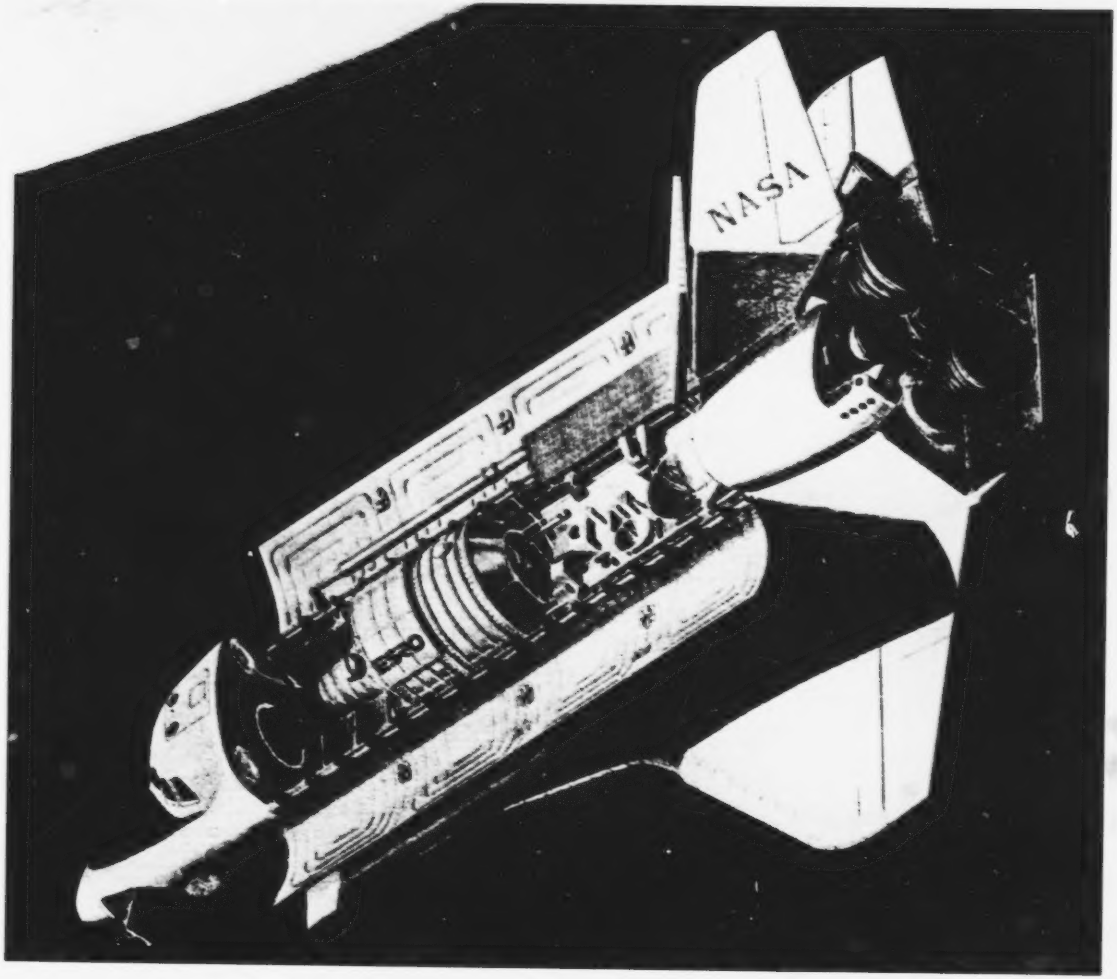
5.2 NASA Resources

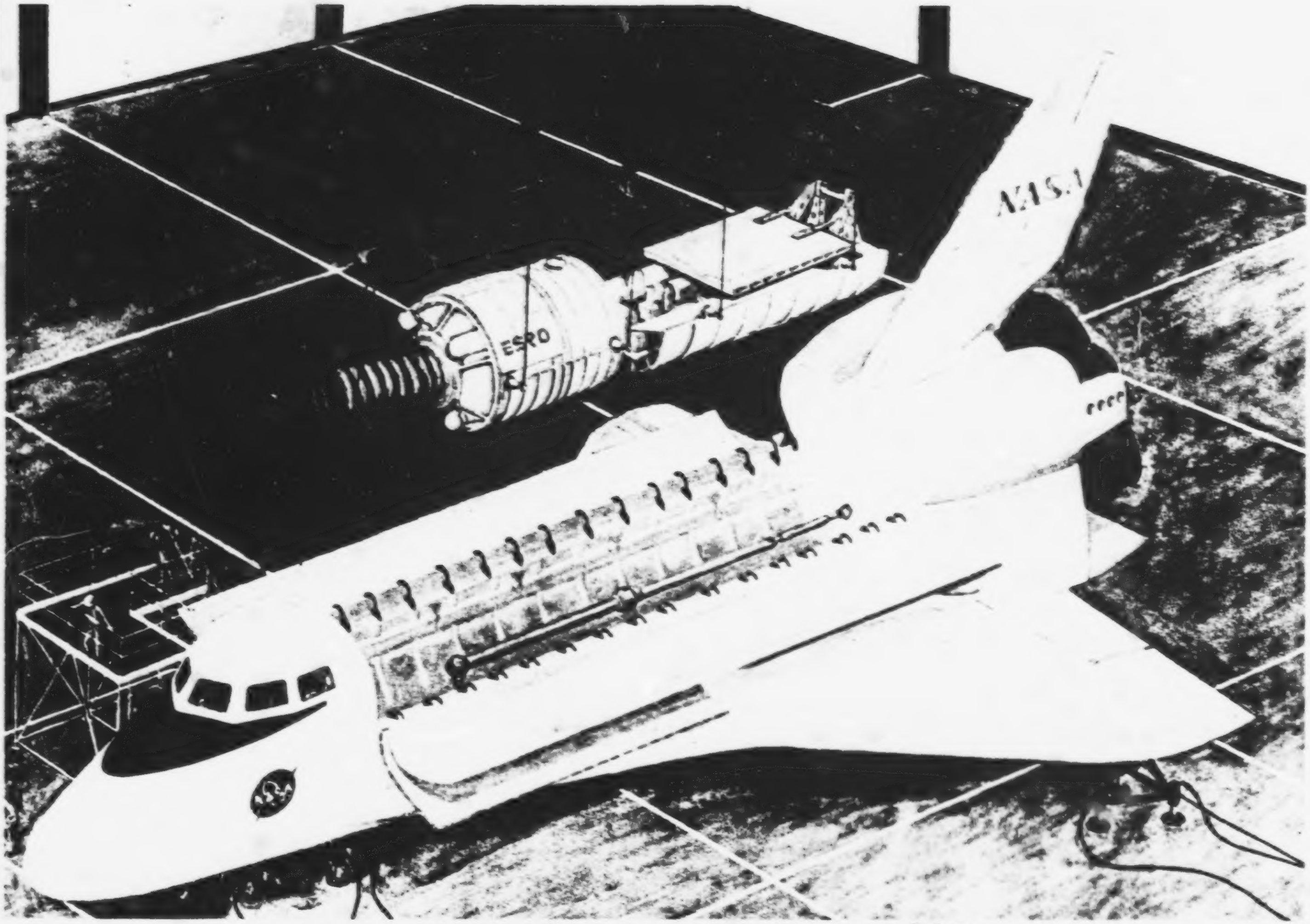
NASA plans to allocate 5.2 billion dollars in the development of the Space Shuttle system over the next six years and has already spent over 600 million dollars as of June 1974. Significant additional funding is planned for Shuttle facilities including modifications to launch facilities, construction of runways, leasing the Tracking and Data Relay Satellite System (TDRSS). In addition, NASA will provide substantial resources both in manpower and dollars directly for the Spacelab Programme prior to operation, including the funds required for Spacelab procurement, crew transfer tunnel development and procurement, crew trainers and Shuttle interface verification equipment development and procurement and a software test and integration laboratory.

(*) One A.U. is defined by 0.88867088 grams of fine gold.

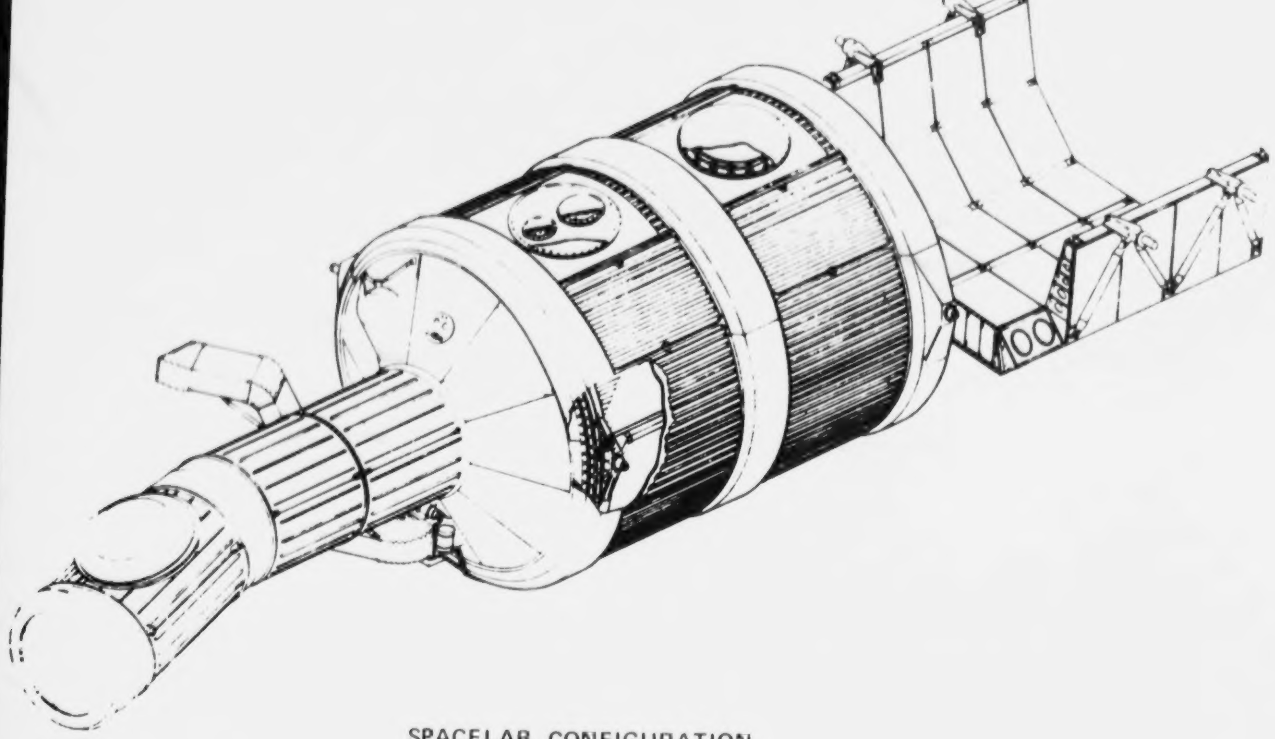
(**) Provisions are made for Austria to participate in the Spacelab Programme with approximately 1 % reducing the percentage of Germany by the same amount.

SPACELAB IN SHUTTLE-ORBITER CARGO BAY



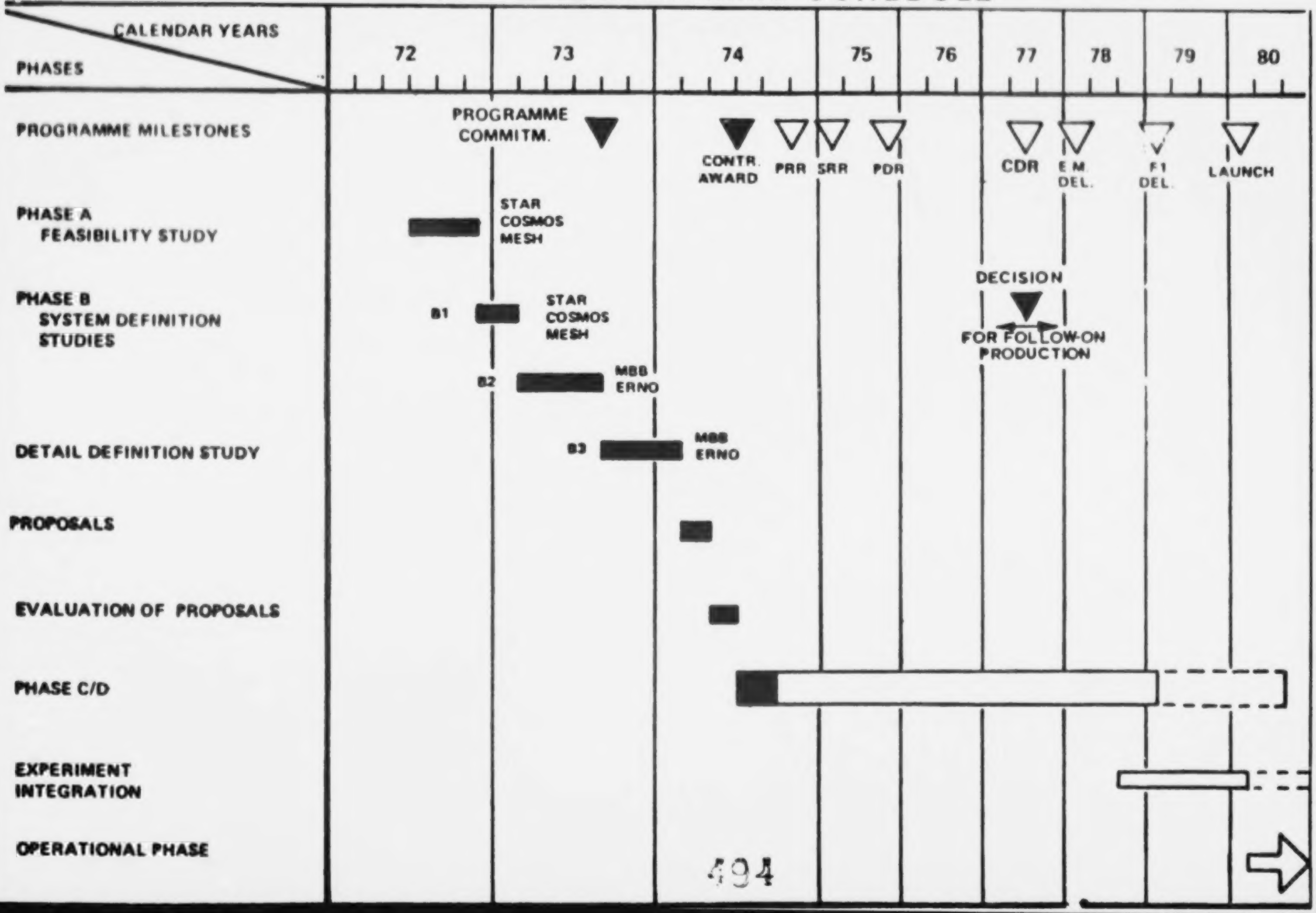


SPACELAB REMOVAL FROM ORBITER

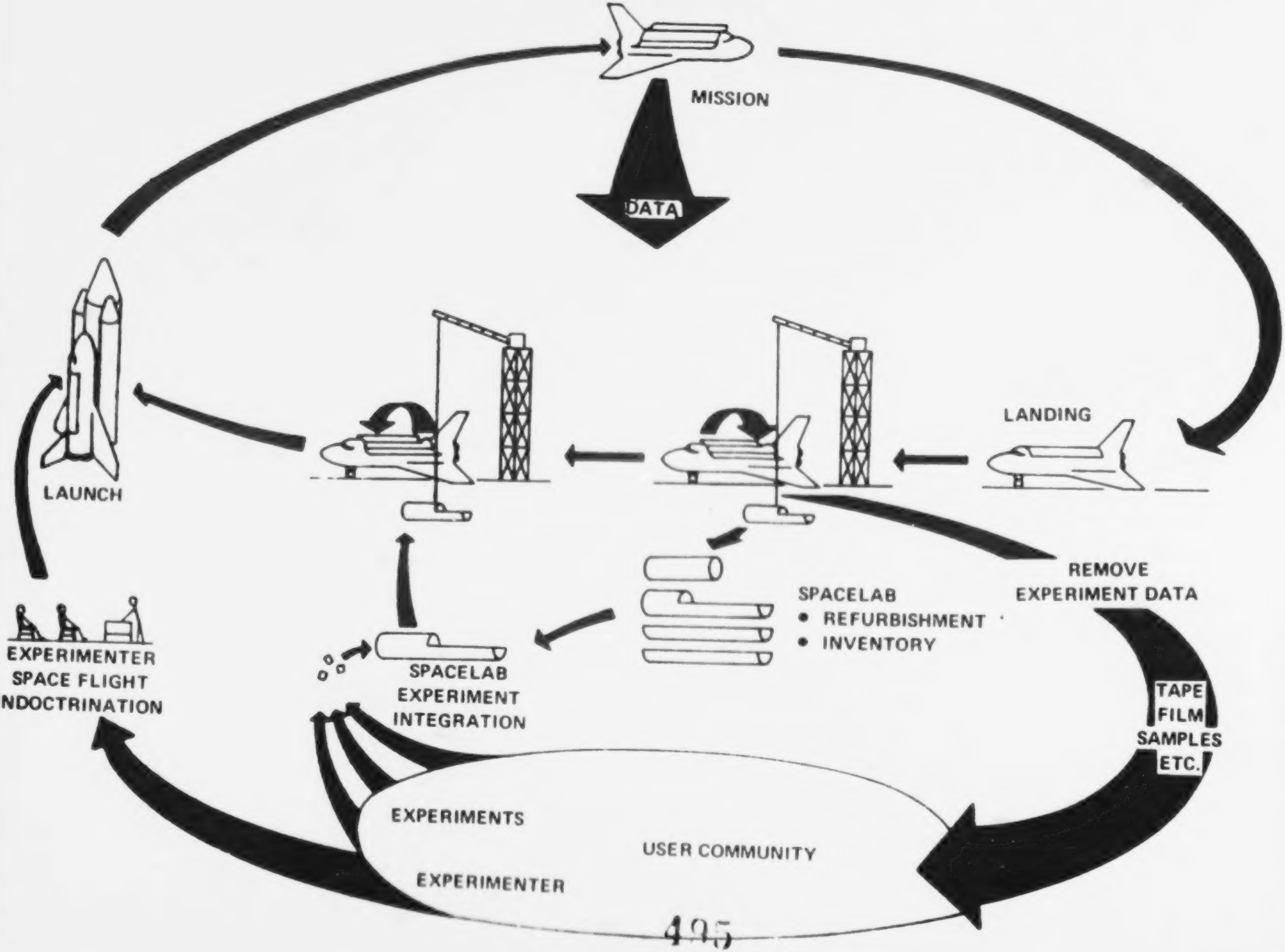


SPACELAB CONFIGURATION

SPACELAB PROGRAMME SCHEDULE



SHUTTLE - SPACELAB FLIGHT PROFILE



MISSION

DATA

LANDING

LAUNCH

REMOVE
EXPERIMENT DATA

SPACELAB
- REFURBISHMENT
- INVENTORY

TAPE
FILM
SAMPLES
ETC.

EXPERIMENTER
SPACE FLIGHT
INDOCTRINATION

SPACELAB
EXPERIMENT
INTEGRATION

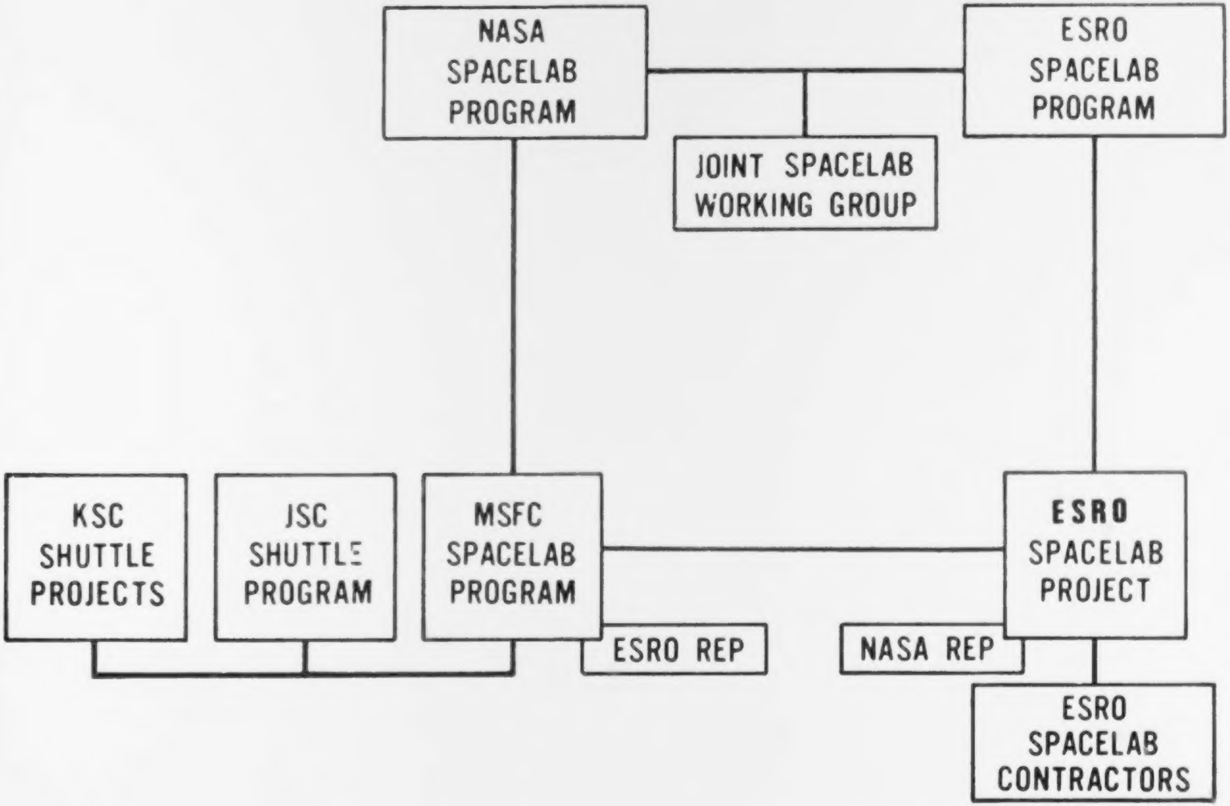
EXPERIMENTS

USER COMMUNITY

EXPERIMENTER

JOINT PROGRAMME PLAN

MANAGEMENT RELATIONSHIPS



NASA SPACELAB PROGRAM

ESRO SPACELAB PROGRAM

JOINT SPACELAB WORKING GROUP

KSC SHUTTLE PROJECTS

JSC SHUTTLE PROGRAM

MSFC SPACELAB PROGRAM

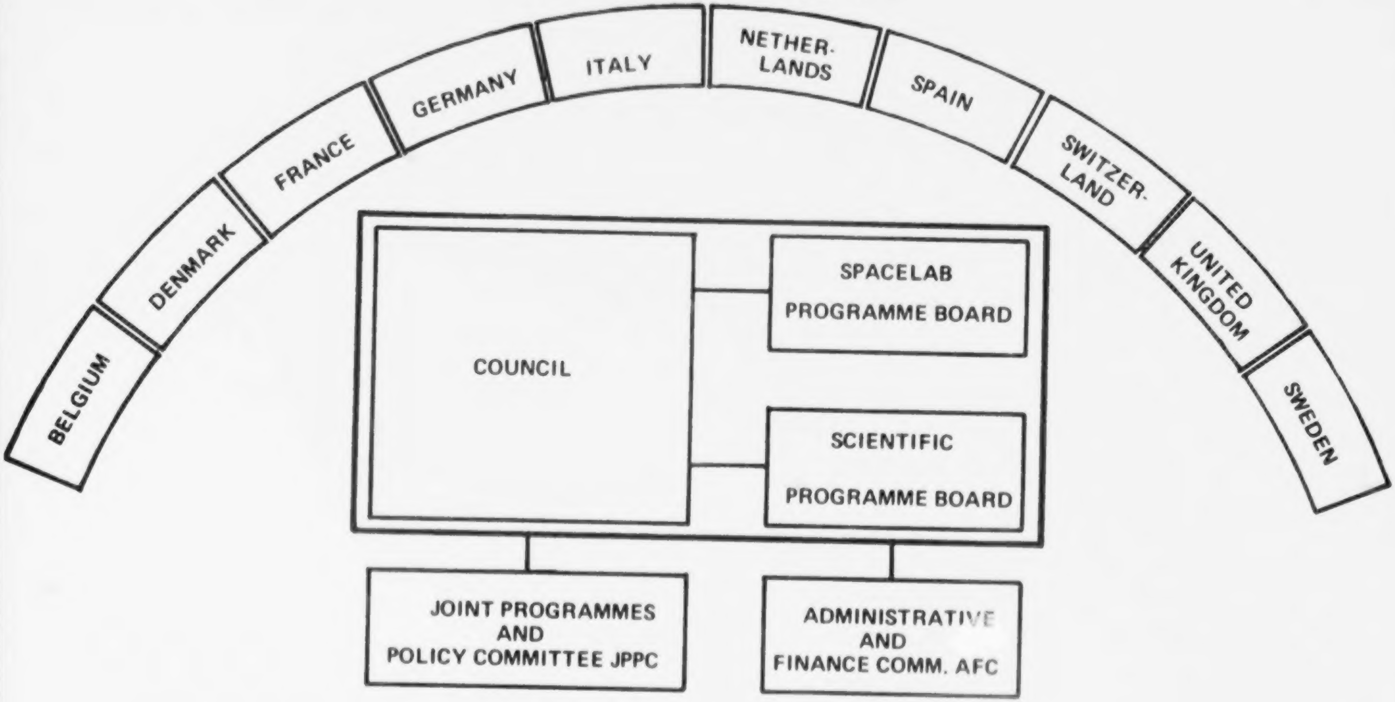
ESRO REP

NASA REP

ESRO SPACELAB PROJECT

ESRO SPACELAB CONTRACTORS

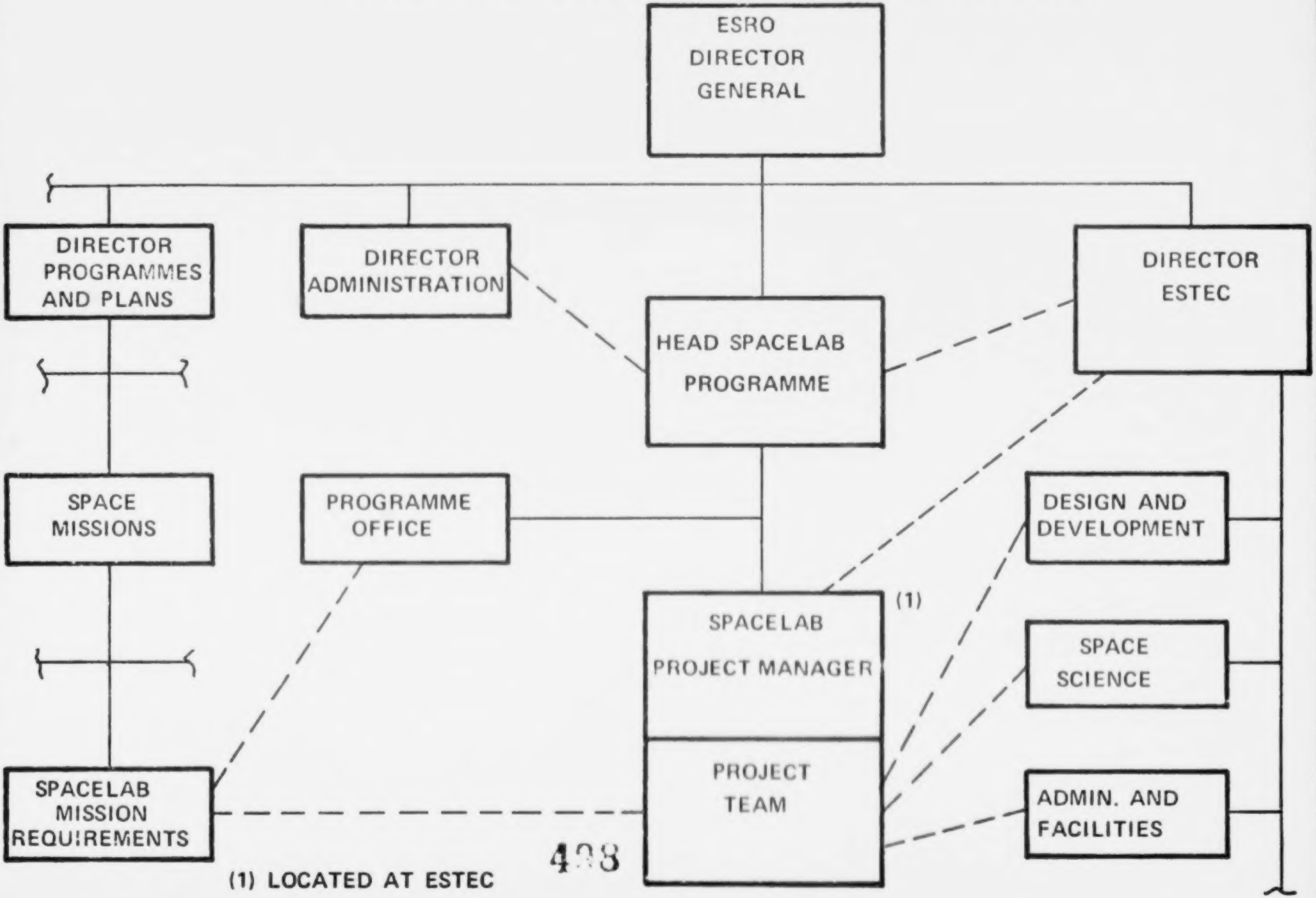
ESRO SPACELAB ORGANISATION


BELGIUM
DENMARK
FRANCE
GERMANY
ITALY
NETHER-LANDS
SPAIN
SWITZER-LAND
UNITED KINGDOM
SWEDEN
COUNCIL
SPACELAB PROGRAMME BOARD
SCIENTIFIC PROGRAMME BOARD
JOINT PROGRAMMES AND POLICY COMMITTEE JPPC
ADMINISTRATIVE AND FINANCE COMM. AFC

ESRO bodies deciding in Spacelab related matters:

Council: Overall decisions and major decisions affecting also other programmes
Spacelab Programme Board: Programme and budget decisions (Sweden not represented)
Scientific Programme Board: Experiment planning decisions for Science
JPPC: Experiment planning decisions for applications and technology
AFC: Contract decisions

SPACELAB ORGANIZATION WITHIN ESRO



ESRO DIRECTOR GENERAL

DIRECTOR PROGRAMMES AND PLANS

DIRECTOR ADMINISTRATION

HEAD SPACELAB PROGRAMME

DIRECTOR ESTEC

SPACE MISSIONS

PROGRAMME OFFICE

DESIGN AND DEVELOPMENT

SPACELAB PROJECT MANAGER (1)

PROJECT TEAM

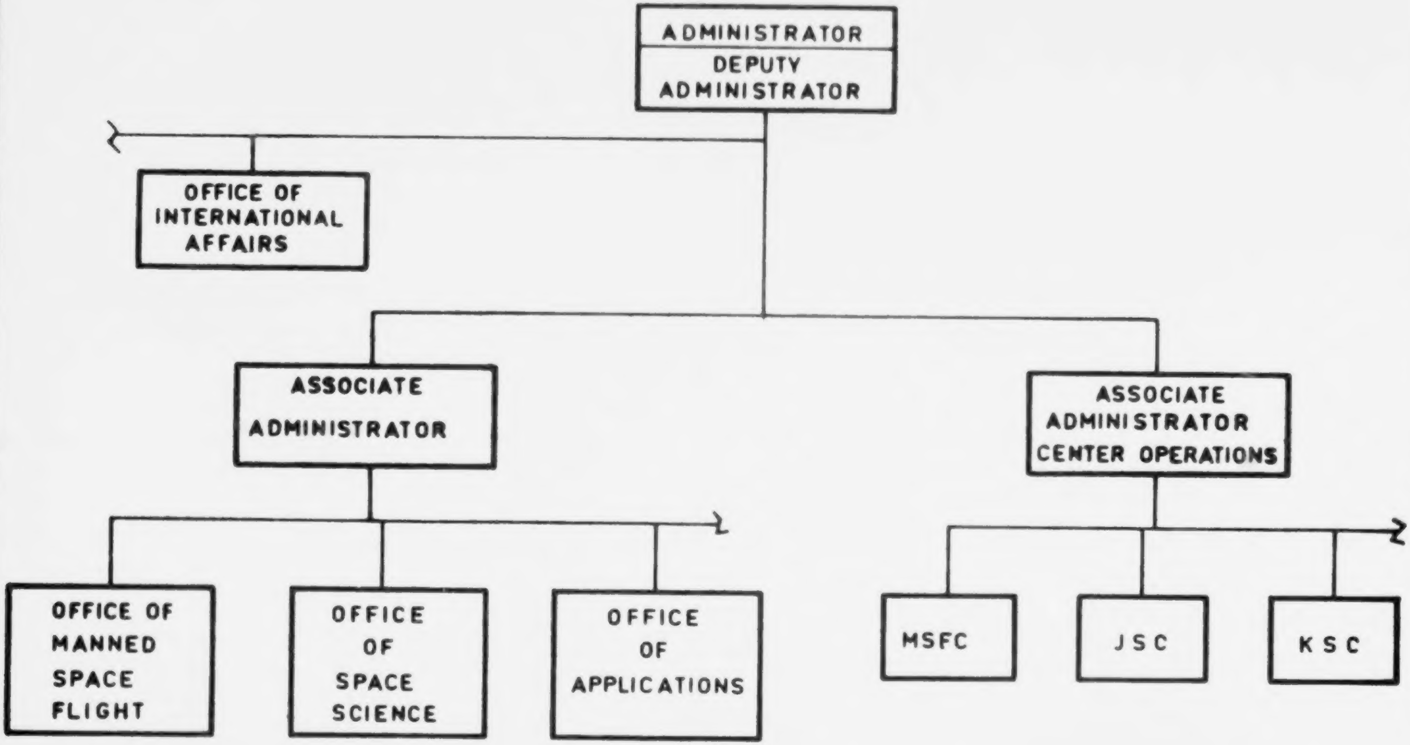
SPACE SCIENCE

ADMIN. AND FACILITIES

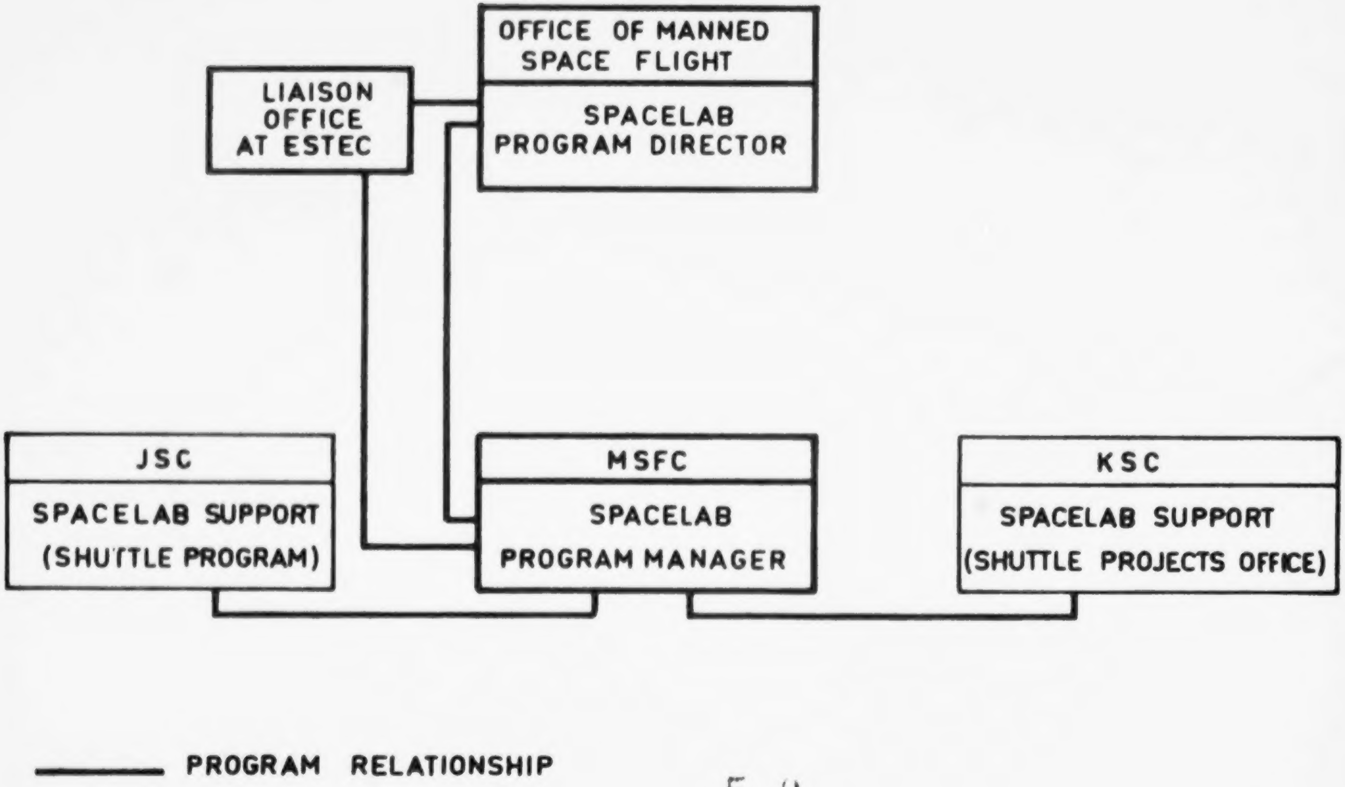
SPACELAB MISSION REQUIREMENTS

(1) LOCATED AT ESTEC

NASA ORGANISATION

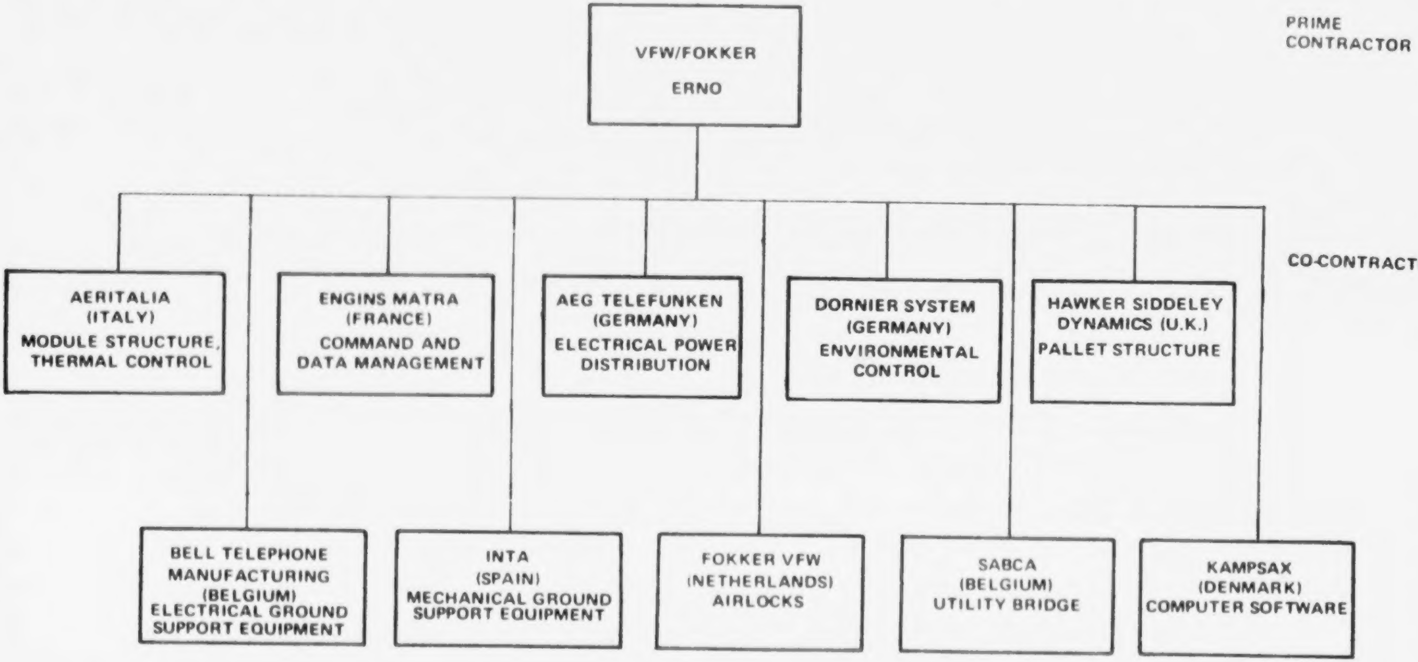

ADMINISTRATOR
DEPUTY ADMINISTRATOR
OFFICE OF INTERNATIONAL AFFAIRS
ASSOCIATE ADMINISTRATOR
ASSOCIATE ADMINISTRATOR CENTER OPERATIONS
OFFICE OF MANNED SPACE FLIGHT
OFFICE OF SPACE SCIENCE
OFFICE OF APPLICATIONS
MSFC
JSC
KSC

NASA SPACELAB ORGANISATION



OFFICE OF MANNED SPACE FLIGHT
SPACELAB PROGRAM DIRECTOR
LIAISON OFFICE AT ESTEC
JSC
SPACELAB SUPPORT (SHUTTLE PROGRAM)
MSFC
SPACELAB PROGRAM MANAGER
KSC
SPACELAB SUPPORT (SHUTTLE PROJECTS OFFICE)
PROGRAM RELATIONSHIP

CONTRACTOR SPACELAB ORGANISATION



PRIME CONTRACTOR

VFW/FOKKER
ERNO

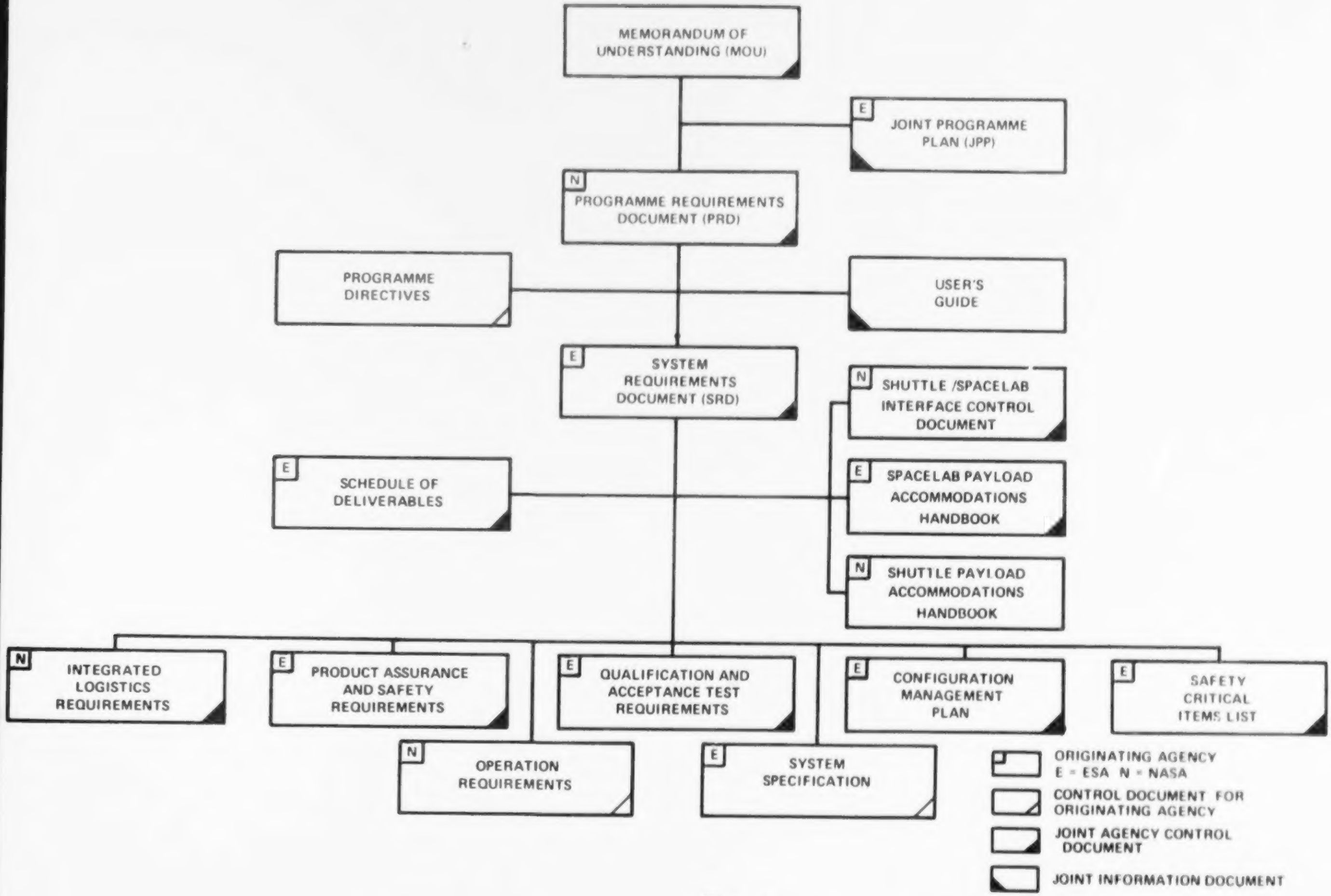
CO-CONTRACTOR

- **AERITALIA (ITALY)** MODULE STRUCTURE, THERMAL CONTROL
- **BELL TELEPHONE MANUFACTURING (BELGIUM)** ELECTRICAL GROUND SUPPORT EQUIPMENT
- **ENGINS MATRA (FRANCE)** COMMAND AND DATA MANAGEMENT
- **INTA (SPAIN)** MECHANICAL GROUND SUPPORT EQUIPMENT
- **AEG TELEFUNKEN (GERMANY)** ELECTRICAL POWER DISTRIBUTION
- **FOKKER VFW (NETHERLANDS)** AIRLOCKS
- **DORNIER SYSTEM (GERMANY)** ENVIRONMENTAL CONTROL
- **SABCA (BELGIUM)** UTILITY BRIDGE
- **HAWKER SIDDELEY DYNAMICS (U.K.)** PALLET STRUCTURE
- **KAMPSAX (DENMARK)** COMPUTER SOFTWARE

DELIVERABLES

End Item	Quantity		Manufacture and Delivery Responsibility	Funding Responsibility		Initial Delivery Date	Delivery To
	Initial	Follow-on		Initial	Follow-on		
Engineering Model 2	1	TBD	ESA	ESA	NASA	TBD	ESA
Instrument Pointing System	TBD	│	│	│	│		NASA
Initial Spares	1/1 Set	│	│	│	│	3Q'78/3Q'79	│
Electrical Ground Support Equipment	1/1 Set	│	│	│	│	TBD	│
Mechanical Ground Support Equipment	1/1 Set	TBD	ESA	ESA	NASA	TBD	NASA
Software (Non-Applications)							│
Flight System	1	N/A	ESA	ESA	NASA	3Q'78	NASA
GSE	1	N/A	ESA	ESA		3Q'78	│
Ground Operations	1	TBD	NASA	NASA		TBD	│
Flight Operations	1	TBD	│	│		│	│
Crew Transfer Tunnel	2	TBD	│	│		│	│
Verification Flight Instrumentation	TBD	N/A	│	│	N/A	│	│
Support Training Equipment	TBD	│	NASA	│	│	│	│
High Fidelity Mockup	TBD	│	ESA	NASA	│	│	NASA
Hard Mockup	TBD	N/A	ESA	ESA	N/A	TBD	ESA

PRINCIPAL SPACELAB DOCUMENTATION


MEMORANDUM OF UNDERSTANDING (MOU)
E
JOINT PROGRAMME PLAN (JPP)
N
PROGRAMME REQUIREMENTS DOCUMENT (PRD)
PROGRAMME DIRECTIVES
USER'S GUIDE
E
SYSTEM REQUIREMENTS DOCUMENT (SRD)
N
SHUTTLE /SPACELAB INTERFACE CONTROL DOCUMENT
E
SCHEDULE OF DELIVERABLES
E
SPACELAB PAYLOAD ACCOMMODATIONS HANDBOOK
N
SHUTTLE PAYLOAD ACCOMMODATIONS HANDBOOK
N
INTEGRATED LOGISTICS REQUIREMENTS
E
PRODUCT ASSURANCE AND SAFETY REQUIREMENTS
E
QUALIFICATION AND ACCEPTANCE TEST REQUIREMENTS
E
CONFIGURATION MANAGEMENT PLAN
E
SAFETY CRITICAL ITEMS LIST
N
OPERATION REQUIREMENTS
E
SYSTEM SPECIFICATION
ORIGINATING AGENCY
E = ESA N = NASA
CONTROL DOCUMENT FOR ORIGINATING AGENCY
JOINT AGENCY CONTROL DOCUMENT
JOINT INFORMATION DOCUMENT

APPENDIX

C

SPACELAB

Programme Requirements

LEVEL I

ESA–SL–74–1
NASA–MF–74–1
Revision 2

September 24, 1975

Douglas R. Lord
Director, Spacelab Program
National Aeronautics and
Space Administration

Bernard Deloffre
Director of Spacelab Programme
European Space Agency

1.0 INTRODUCTION

The purpose of this document is to establish the Level I programme requirements for the Spacelab Programme. The Level I programme requirements are originated by NASA and approved by ESA. Once established, the programme requirements are jointly controlled by the Director, Spacelab Programme (ESA) and the Director, Spacelab Program (NASA) as necessary to achieve the principal programme objectives:

(1) to provide a versatile capability for accommodating laboratory and observatory facilities suitable for Space Shuttle sortie flights at the lowest practical investment, both in development and operating costs.

(2) to reduce significantly both the time and cost required for space experimentation.

(3) to make direct space research possible for qualified scientists and engineers without the need for full astronaut training.

This document sets forth in sections 1.0 through 8.0 the top level definitions, requirements and philosophy for design, operation, product assurance and safety. Level I programme implementation requirements are given in sections 9.0 through 12.0. The PRD is consistent with the overall programme described in the reference 12.2(a) and is the principal controlling document on the Spacelab Programme; all planning, direction and implementation shall be in accord with requirements stated herein. Additional Level I direction to the programme may be introduced by changes to the PRD, or, in special cases, in the form of Programme Directives, as required.

The content of this document applies to the design and development of Spacelab, its supporting equipment, facilities and software, and to its operations planning. Except where directly referred to, experiments are excluded from the specific requirements postulated. In particular, the requirements of sections 7.8 are not applicable to experiment equipment.

2.0 GENERAL

2.1 DEFINITIONS

2.1.1. Spacelab Programme includes the definition, design, development, manufacture and production of pressurized modules and external platforms (pallets), GSE, common payload support equipment, mock-ups, simulators, trainers, software and the equipment needed to interconnect the Spacelab module and/or the Spacelab pallet to the Space Shuttle Orbiter. The programme also includes planning for: (1) ground operations, involving experiment integration, checkout and test and maintenance; and (2) flight operations associated with the crew, the Spacelab, and typical experiments, including mission control, crew training and data management.

2.1.2. Spacelab is composed of modules and pallets suitable for accommodating instrumentation for conducting science, applications and technology activities on Shuttle sortie flights. On a given flight the Spacelab configuration can be comprised of a module only, a pallet only, or a combination of a module and a pallet. Spacelab will always remain attached to the Shuttle Orbiter throughout its flight.

2.1.3. A Spacelab module is a pressurized manned laboratory suitable for conducting science, applications and technology activities on Space Shuttle sortie flights. The segment of the module which is devoted primarily to subsystem support to experiments in the module or mounted on the pallet is called the core segment. An additional segment may be devoted primarily to housing experiment equipment and activities and will be called the experiment segment. The Spacelab module may therefore fly either as a short module (core segment only), or a long module (with experiment segment).

2.1.4. A Spacelab pallet is an unpressurized platform for mounting telescopes, antennae and other instruments and equipment requiring direct space exposure for conducting science and applications activities on Space Shuttle sortie flights. The pallet experiments will be operated automatically or remotely from the Spacelab module, the Orbiter cabin or directly from the ground. In each case an adequate interface for subsystem support will be provided. Two or more pallet segments may be mounted in series. The complete assembly is then called a pallet train. In the pallet only mode, the pallet train is flown without a module. In this case, an interface unit called an igloo will be provided with support subsystems in one or more pressurized compartments.

2.1.5. A Spacelab flight unit comprises all system constituents necessary to assemble any flight configuration.

2.1.6. The Engineering Model is a full size structural model, dimensionally correct (including interfaces), with subsystems functionally identical to the flight unit (but not necessarily fully qualified), and comprises all system constituents necessary to assemble any flight configuration. The module will represent the flight unit in all respects as it is known at the time of Intermediate Design Review (IDR) and its configuration will be maintained to reflect the flight configuration.

2.1.7. A sortie flight is of relatively short duration (nominally seven (7) days extendable up to thirty (30) days) and is conducted in low earth orbit using the Shuttle Orbiter and equipment attached to it for experiments, observations and other space activities.

2.1.8. Baseline - A fundamental reference with regard to programme plan, configuration, operations and experiments and the basis for comparison of alternatives.

2.1.9. Fail safe - defined as the ability to sustain a failure and retain the capability of terminating a flight without injury to crew personnel or vital Spacelab subsystems.

2.1.10. Acceptance - the formal process governing the delivery of hardware and software.

2.1.11. Ground Support Equipment (GSE) - includes all Spacelab specific equipment and software required for transporting, ground handling, testing, integrating, refurbishing, reconfiguring, checkout, prelaunch and post-landing operations. This also includes simulators needed for verification and checkout of interfaces.

2.1.12. Transfer Tunnel - a variable length tunnel providing access to the Spacelab module from the Orbiter and also to an EVA hatch.

2.1.13. Common Payload Support Equipment (CPSE) - equipment other than basic Spacelab and Shuttle subsystems, such as a scientific airlock, needed by more than one Spacelab experiment.

2.1.14. Racks - removable/reusable assemblies that provide structural mounting and connections to supporting subsystems (power, thermal control, data management, etc.) for experiment equipment which is housed in the pressurized module.

2.1.15. Flight Success is defined as the proper functioning of the Spacelab, its subsystems, and the experiment support equipment provided to the users (but not of the experiments themselves).

2.2 UNITS

Drawings, specifications, weight statements and summary engineering data will utilize the International System of Units (M.K.S.A.). Both International Systems of Units and common British engineering units will be used in Shuttle/Spacelab interface documents and drawings. The use of both systems of units in other areas will be mutually agreed upon by ESA and NASA.

3.0 SYSTEM

3.1 DESIGN MISSIONS

3.1.1. Spacelab will be designed for Experiment Missions supporting multidiscipline or single discipline science, applications and technology. The experiment objective may constitute a total Shuttle flight objective or may be combined with other major flight objectives (refer to par. 3.1.2). Orbital inclinations and altitudes of Experiment Missions shall be compatible with Orbiter capabilities:

Inclinations	28.5° to 57° for ETR 56° to 104° for WTR
Altitudes	Minimum TBD (circular orbit) Maximum TBD (circular orbit) TBD (elliptical orbit)

3.1.2. The Spacelab design shall not preclude Satellite Deployment and Retrieval Missions which can be conducted on the same flights as experiments.

3.2 DESIGN LIFE

As a design objective, Spacelab shall be capable of use for a minimum of 10 years and of low cost refurbishment and maintenance for approximately 50 flights of 7 days duration.

3.3 FLIGHT SUCCESS

3.3.1. The Spacelab will be designed for a high probability of flight success. The goal will be 0.95 (independent of Shuttle and Network reliability) for 7-day flights.

3.3.2. The redundancy requirements for all Spacelab subsystems (except primary structure and pressure vessels) shall be established on an individual basis, but shall not be less than fail safe for all subsystems. Primary structure and pressure vessels shall be designed for safe life (refer to par. 3.2).

3.4 CREW

3.4.1. The Spacelab crew (men and women) will consist of one to four "payload specialists" who may be principal investigators and may have minimal astronaut-type training. These are in addition to the Orbiter crew which consists of a commander, pilot and mission specialist.

The mission specialist will be the principal onboard expert for both Orbiter and Spacelab basic subsystems and will monitor, control, activate, trouble shoot, maintain and deactivate these subsystems as required. He will also assist the payload specialist on a time available basis. The commander and pilot will operate the Orbiter in support of the flight and will assist the mission specialist and payload specialists on a time available basis.

3.4.2. For design of the Spacelab, the following numbers of personnel shall be considered:

Total in orbit	Available for Spacelab activities-full time basis
Maximum 7	4
Minimum 4	1

The Spacelab module will be designed to accommodate up to three persons continuously and up to four persons during crew shift overlap. The Shuttle Orbiter will provide sleep, galley, waste management, personal hygiene, health and well being accommodations as well as seating during ascent, reentry and landing for all crew members.

3.4.3. The weight of all personnel in excess of four including the weight of their seats, equipment and provisions (normal and emergency) will be chargeable to Spacelab. Expendable provisioning for 28 man-days is provided by the Orbiter and provisioning storage capacity (but not the expendables themselves) is also provided for an additional 14 man-days.

3.5 WEIGHT AND CENTER OF GRAVITY

3.5.1. The total design weight of Spacelab including:

- Mission independent subsystem support (essential subsystems);
- Mission dependent subsystem support (CPSE, recorders, etc.);
- Transfer tunnel;

- Mission independent Orbiter support equipment (one energy kit, heat rejection kit, and bridge fittings);

- Spacelab payload (experiment equipment, instrument pointing systems, crew members and crew provisions in excess of four, non-expendable provisions for missions longer than seven days, and any Orbiter provided mission dependent support equipment such as OMS kits, second manipulator and TDRSS antenna, etc.);

- Program weight reserve;

but excluding expendables will not exceed 14,515 kg (32,000 lbs).

The total Spacelab launch weight may exceed 14,515 kg up to the limit set by the Space Shuttle system launch capability for the particular mission but in no case exceed 29,484 kg (65,000 lbs).

3.5.2. The following weight will be available for Spacelab payload on all seven-day missions:

Configuration	Spacelab Payload Weight	
Long Module	5500 kg	(12,125 lbs)
Short Module + 9m Pallet	5500 kg	(12,125 lbs)
Pallet only, 15m	8000 kg	(17,610 lbs)
Pallet only, 9m	9100 kg	(20,065 lbs)

The above payload weight requirements are applicable using the Hardware Limit Weight (refer to par. 3.5.3), but not including the payload growth reserve and non-allocated reserve. Variations resulting from user requirements on specific missions will result in upwards or downwards adjustments to the payloads.

3.5.3. Spacelab hardware and Orbiter support equipment will not exceed the Hardware Limit Weight. The Hardware Limit is the sum of the weights and reserves controlled at or below Level II and includes the basic Spacelab, tunnel (where applicable), 50% of mission dependent equipment available for that configuration and Orbiter support equipment. It is the intent of both ESA and NASA that at least the values listed below be reserved for payload growth.

	Hardware Limit	Payload Growth Reserve	
Configuration	kg	kg	% of pay. req.
Long Module (long tunnel)	7326	1100	20%
Short Module + 9m Pallet	7884	1100	20%
*Pallet only 15m	4982	1533	19.2%
**Pallet only 9m	4046	1369	15%

---

*Pallet suspended in two groups: 2 segments and 3 segments

**Pallet segments separately suspended

3.5.4. The combination of weight and center of gravity for the Spacelab (as defined in 3.5.1.), with and without expendables, must fall within the limits specified in reference 12.2(d) during both ascent and reentry.

3.6 LIMITING DIMENSIONS

The dynamic envelope of Spacelab and tunnel shall not exceed a cyclinder of 4.57 m (15 ft) in diameter (except for mounting fittings), and 18.29 m (60 ft) in length (or less when particular flights require items such as Orbital Maneuvering System propellant kits).

3.7 MODULE SIZE

The size of the minimum module will be such that it accommodates approximately 5 m^3 (175 ft^3) of experiment equipment volume. The size of the largest module will be subject to the requirement for a cyclindrical side wall length of approximately 4.5 m (14.8 ft) fully available for experiment use.

3.8 PALLET SIZE

As a design goal a length of 15 m (49 ft) should be achievable with combined pallet segments.

3.9 TRANSFER TUNNEL

3.9.1. The transfer tunnel will be sufficiently variable in length to accommodate the most extreme positions of the Spacelab pressurized module in the Orbiter payload bay required to meet center of gravity constraints.

3.9.2. The tunnel will also permit ground installation of a docking module at the forward end of the payload bay for special flights.

3.9.3 The transfer tunnel will mate with a tunnel adapter and a personnel airlock at the forward end of the payload bay which will provide access to the payload bay for scheduled and unscheduled EVA and for rescue EVA, except on special missions carrying a docking module.

3.9.4. The tunnel will be designed in such a manner as to permit installation of secondary payloads above it.

3.9.5. The tunnel design will ensure minimum impact on the overall Spacelab in terms of weight and subsystems support.

3.10 SPACELAB SUBSYSTEMS - GENERAL

(Also see section 5.0)

3.10.1. The use of available subsystems, assemblies and components in the Spacelab, and all necessary flight and ground support equipment shall be considered. These items may include standard commercial and military components and those developed for other programmes including the Shuttle. Availability of additional units and spares during this operational phase is an important consideration.

3.10.2. Subsystems will not normally require ground operations support and monitoring during orbital operations.

3.10.3. The crew time required for subsystem monitoring, control and on-orbit maintenance will be minimized.

3.10.4. The design of the core segment and the igloo will facilitate the functional separation of resources management from payload data management in both flight and ground operations.

3.10.5. Limited support to payloads during prelaunch, launch, reentry and post-landing periods, over and above the basic capabilities of the Orbiter and Spacelab subsystems will be provided by the Spacelab, the Shuttle, and/or the payloads.

3.10.6. To tne extent to which it will facilitate turnaround activities and minimize ground and flight crew time spent in housekeeping activities, the Spacelab design will include the capability for remote activation and control of the flight subsystems.

3.11 SPACELAB SUBSYSTEMS - SPECIFIC

3.11.1. Spacelab air revitalization subsystem (ARS) will provide an oxygen/nitrogen mixture at one atmosphere pressure and will be able to operate with all hatch doors open or closed between the Orbiter cabin and the module.

3.11.2. The Spacelab module will have:

(a) Nearly continuous real-time wide band digital, analog and video data transmission through the Orbiter and a relay satellite (TDRSS).

(b) High data rate recording, digital, analog and video.

(c) Tape and film storage.

3.11.3. As a goal the command and data management subsystem (CDMS) will minimize the need for ground support equipment.

3.11.4 The Spacelab will have its own command and data management subsystem with dedicated computers to perform subsystem functions separately from experiment functions. The Spacelab CDMS will function independently of the Orbiter computers except for initial activation and resources management.

3.11.5. A precision instrument pointing subsystem (IPS) which can be mounted on the pallet will be provided.

3.12 MARGINS

Where possible, safety factors and design margins will be sufficiently large to minimize a costly verification and qualification effort during the development phase or retesting during the operational phase.

3.13 EXTENDED FLIGHT DURATION

The Spacelab will incorporate design provisions to extend the flight duration up to 30 days including all necessary stowage compartments, volume and distribution systems for expendables and subsystem maintenance and redundancy features.

3.14 LABORATORY VERSATILITY

3.14.1. The Spacelab module and pallet will be configured to provide the maximum versatility for experiment payload accommodation.

3.14.2. Laboratory utility to the users will be a major consideration in all design and operational concept decisions.

3.14.3. As a goal, the facilities provided by the Spacelab will accommodate users' science, applications, and technology equipment with minimum costs to the users for modification or adaptation.

3.15 COMMON PAYLOAD SUPPORT EQUIPMENT (CPSE)

The flight units will include at least the following CPSE:

(a) two large removable scientific airlocks.

(b) one high quality window and one view port for science, applications, and technology observations.

(c) one or more work benches.

(d) a film vault.

(e) a vacuum vent.

3.16 DEPLOYMENT

All Spacelab related devices which are extended on orbit out of the payload bay must have emergency provisions for retraction or jettison.

3.17 HABITABILITY

The Spacelab module will provide the crew with comfortable, efficient and safe working conditions with easy access to the living quarters in the Space Shuttle Orbiter. The module will provide a shirtsleeve environment and will be pressurized to one atmosphere.

3.18 INTERNAL ARRANGEMENT

The internal arrangement of the Spacelab module will be generally suitable for a gravity (single orientation) environment with the floor(s) parallel to the cyclinder axis in order to facilitate:

- experiment installation at a user's home site with minimum fixtures and scaffolding;
- refurbishment and turnaround operations;
- rapid crew familiarization and training;
- mission simulation using the flight articles.

3.19 ACCESSIBILITY AND MAINTAINABILITY

3.19.1. Easy on-the-ground accessibility to the Spacelab subsystems and experiment racks is a requirement.

3.19.2. On-the-ground maintenance will be the primary maintenance mode.

3.19.3. On-orbit accessibility will be provided to experiments requiring servicing or maintenance and to subsystems that may require nonscheduled maintenance. Appropriate hand and foot holds for both internal and EVA operations will be provided.

3.19.4. Spacelab and removable GSE will be designed to provide limited access for experiment servicing during ground operations in a vertical position. As a goal, access to experiments in the module will be possible up to 4 hours before launch and immediately after landing.

3.19.5. Direct access into the module during launch pad operation will optionally be possible in addition to the access provided by the transfer tunnel. (refer to par. 7.5.4)

3.20 INTEGRATION

Integration and mating of all Spacelab elements must be simple and reliable.

3.21 GROUND HANDLING AND TRANSPORTABILITY

3.21.1. As a goal the design of Spacelab elements (modules, module segments, pallets, pallet segments, racks, etc.) and the necessary containers and other GSE will permit as many different ground shipment options as practical.

3.21.2. Individual Spacelab elements (e.g. experiment segments,pallet segments, rack sets) will be transportable in a C5A aircraft.

3.21.3 In order to facilitate complete experiment integration at the homesite of a user organization the combined Spacelab experiment equipment and experiment mounting elements (e.g. racks and pallet segments) will be compatible with shipment in a C5A aircraft.

3.22 GROUND SUPPORT EQUIPMENT (GSE)

3.22.1. In addition to the GSE required for development and at the launch/landing sites, GSE will also be needed for:

(a) experiment payload integration (excluding experiment unique GSE).

(b) operation of the Engineering Model.

(c) transportation of the complete Spacelab and Spacelab elements as required.

3.22.2 As a goal all transportation and handling equipment shall be designed to provide environments in ground operations less severe than those experienced in flight. Environment monitoring during shipment is a requirement.

3.23 CONTAMINATION

Spacelab will be designed to minimize the generation, introduction and accumulation of gaseous and particulate contaminants, both internal to the module and external to the module and pallet. The external contamination level on Spacelab missions will be consistent with the Shuttle Orbiter payload bay. Spacelab will minimize particle and fluid impingement into the payload bay or any element of the Spacelab or experiment equipment.

3.24 ELECTROMAGNETIC INTERFERENCE (EMI)

The Spacelab design should minimize the generation of EMI from sources within the Spacelab. As a goal it will also afford protection to Spacelab subsystems and payloads from EMI being introduced into Spacelab from external sources.

3.25 SOFTWARE

3.25.1. As a goal Spacelab software for both subsystem and experiment support will conform to NASA Space Flight Software Standards (TBD).

3.25.2. As a goal Spacelab software for both subsystem, and experiment support will be compatible with host computers in use at NASA and ESA installations. (refer to par. 3.11.4)

3.25.3 Data exchange between Spacelab and the Orbiter will be formatted to be compatible with the Orbiter.

3.26 SYSTEM QUALIFICATION

The Spacelab will be qualified on the ground insofar as practical, prior to acceptance of the First Flight Unit. Adequate test hardware (non-deliverable to the U.S.) is required for successful implementation of the project. As required, design and environment verification will be conducted on early flights.

3.27 ENVIRONMENT

3.27.1. Natural environment data as specified in reference 12.2(g) will be used for design and operational analyses.

3.27.2. The environments experienced by the Spacelab associated with flight operations are contained in reference 12.2(d) and subsequent revisions thereto.

3.28 COMMONALITY

Commonality of flight and ground components, spares and tools within Spacelab subsystems and associated GSE will be established where practical. Also an effort will be made to optimize commonality between Spacelab and Shuttle components. In addition, consideration shall be given to common use of facilities, operating systems, software and associated support with the Shuttle as applicable.

4.0 OPERATIONS

4.1 GROUND OPERATIONS

4.1.1. The major steps (integration levels) in ground operational processing of Spacelab following refurbishment and of its experiment payloads are:

Level I - integration and checkout of the Spacelab and its payloads with the Shuttle Orbiter, including the necessary preinstallation testing with simulated interfaces.

Level II - integration and checkout of the combined experiment equipment and experiment mounting elements (e.g. racks, rack sets and pallet segments) with the flight subsystem support elements (i.e. core segment, igloo) and experiment segments, when applicable.

Level III - combination, integration and checkout of all experiment mounting elements (e.g. racks, rack sets and pallet segments) with experiment equipment already installed, and of experiment and Spacelab software.

Level IV - integration and checkout of experiment equipment with individual experiment mounting elements (e.g. racks and pallet segments).

4.1.2. Level I integration will always take place at the launch site.

4.1.3. Refurbishment and Level II integration will normally be performed at the launch site.

4.1.4. Level III integration will be possible at various spacecraft and payload development facilities (NASA and ESA centers, other government organizations, industrial concerns, and universities). However, extensive Spacelab GSE and facilities may be required.

4.1.5. Level IV integration will be possible at user home facilities with minimum Spacelab unique GSE.

4.1.6. Spacelab will normally be installed and removed from the Orbiter while the Orbiter is in a horizontal attitude.

4.1.7. Spacelab will also be designed for rapid removal from the Orbiter while in a vertical attitude on the launch pad.

4.1.8. Spacelab ground operations shall be as independent of the Orbiter as practical.

4.1.9. The goal for ground turnaround, when Spacelab is fully operational, from the time of landing to launch for refurbishment of flight subsystem support elements (i.e. core segment, igloo), and for Level II and I integration including final prelaunch activities will be 320 working hours.

4.2 FLIGHT OPERATIONS

4.2.1. Flight operations control of core segment and igloo resources will be the responsibility of Shuttle flight control (which includes the basic Orbiter crew).

4.2.2. Ground support for Spacelab housekeeping is expected to be minimal (refer to par. 3.10.2).

4.2.3. Communications and mission control will be through the Mission Control Center at JSC.

4.3 PAYLOAD OPERATIONS

4.3.1. While on-orbit Spacelab experiment operations and experiment data acquisition will be coordinated by a payload specialist.

4.3.2. Control of experiment operations may be from various payload development centers. Ground support of experiment operations will provide a capability for mission planning, real-time mission replanning, experiment operations training, data preprocessing, and interaction between the payload specialists on orbit and their colleagues on the ground.

4.4 COMMUNICATIONS NETWORK

A Tracking and Data Relay Satellite System (TDRSS) will be used for communications during orbital operations. The characteristics of the NASA communications system with the earth are described in reference 12.2(h).

4.5 EXTRAVEHICULAR ACTIVITY (EVA)

4.5.1. EVA may be used on Spacelab flights for non-scheduled maintenance and repair of subsystems and experiment equipment and also as part of the experiment operation.

EVA will be used for rescue (refer to par. 7.5) except on special missions carrying a docking module.

4.5.2. On Spacelab missions utilizing the module, egress will be through the tunnel adapter and personnel airlock except on special flights on which a docking module is carried.

4.5.3 The Spacelab system design shall not preclude concurrent EVA operations and manned experiment operation in the module.

5.0 SHUTTLE INTERFACE

5.1 COMPATIBILITY REQUIREMENT

The Spacelab to Space Shuttle interface shall comply with reference 12.1(f) when jointly approved. For areas not specifically covered by the ICD, the Spacelab and its experiment payloads will be generally compatible with the Space Shuttle as defined in references 12.2(b) and 12.2(d).

5.2 GROUND INTEGRATION CONSTRAINT

The subsystem support to Spacelab from the Shuttle Orbiter and the interface between the Orbiter and the Spacelab module or pallet shall be consistent with the allocated timeline during Spacelab to Orbiter integration.

5.3 SPACELAB CONFIGURATION IMPACT

Insofar as possible, the design of the various Spacelab configurations (pallet-only, module-only and module pallet combination) will minimize the need for different or additional interface provisions with the Orbiter.

5.4 SHUTTLE SUPPORT TO SPACELAB

Spacelab will depend on the Shuttle Orbiter for:

(a) transportation to and from orbit.

(b) crew accommodations for sleeping, eating, personal hygiene, health and well being, waste management and emergency refuge.

(c) one payload specialist work station on the flight deck with standard racks (2 square meters of panel area, 1 cubic meter of volume).

(d) primary power supply of 7 kw_e average and 12 kw_e peak (15 minutes maximum) on single bus.

(e) a basic energy supply to 50 kwh supplemented by energy kits of 840 kwh each.

(f) basic stabilization and control.

(g) guidance and navigation.

(h) maintenance of the desired orbit.

(i) heat rejection up to 8.5 kw_t with coolant of 7.2°C maximum with a coolant return of 40°C maximum.

(j) normal communications with the ground (refer to par. 3.11.2.).

(k) operational EVA (suits, equipment, expendables and trained crewmen) for 2 two-man operations.

(l) rescue operations and equipment (refer to par. 7.5).

(m) oxygen supply for Spacelab air revitalization subsystem.

(n) master timing signal.

6.0 USER REQUIREMENTS

To the extent practical, the user requirements defined by the NASA-ESA Joint Users Requirements Group (JURG) and documented in reference 12.2(f) will be incorporated into this document (the Programme Requirements Document) and the Spacelab System Requirements Document (reference 12.1(d)).

7.0 PRODUCT ASSURANCE AND SAFETY

7.1 HAZARD IDENTIFICATION, REDUCTION AND CONTROL

Potential hazards will be identified on all Spacelab equipment and operations (ground and flight) including:

(a) interfaces with the Shuttle Orbiter, experiments and GSE.

(b) back-up and emergency operational modes.

Every attempt shall be made to eliminate potential hazards. Those hazards that cannot be eliminated shall be reduced or controlled to an acceptable risk level and flagged as residual hazards. The disposition of hazards will be an important part of all programme design reviews.

7.2 SAFE FLIGHT TERMINATION

As a goal no credible hazard associated with the Spacelab or its experiment activities shall prevent safe termination of a flight.

7.3 SELF-CONTAINED PROTECTION

The Spacelab shall have self-contained protective devices or provisions against all credible Spacelab generated hazards.

7.4 EXPERIMENT HAZARD CONTROL

The Spacelab will have specific equipment, devices and procedures:

(a) to protect the Spacelab, Space Shuttle and crew from whatever hazards may be generated by the science and applications experiment activities.

(b) to relieve the user of as much of the cost of space qualifying and man-rating his or her equipment as practical.

7.5 RESCUE PROVISIONS

7.5.1. Provisions for rescuing the full crew on-orbit will be primarily the responsibility of the Shuttle. The Orbiter cabin will serve as the refuge until a rescue Shuttle arrives. The prime rescue mode will be EVA (refer to par. 4.5.1.) to another Shuttle Orbiter.

7.5.2 The tunnel adapter and personnel airlock will be one of the primary rescue routes from the Orbiter cabin.

7.5.3 The Spacelab module will provide for emergency exit via the transfer tunnel to the Orbiter cabin.

7.5.4 Rapid egress from the Spacelab module will be possible on the launch pad when the Orbiter payload bay doors are open (refer to par. 3.19.5).

7.6 CAUTION AND WARNING SUBSYSTEM

The Spacelab shall be equipped with an independent, hard-wired and automated system for emergency caution and warning (CW) parameters. The CW system will (1) monitor the performance of itself and other Spacelab safety critical systems, and (2) alert the crew to failures and/or out of limit situations which would constitute (or which could result in) an unacceptable hazard to the crew. The signals shall be displayed in the Spacelab module and shall be provided to the Orbiter caution and warning system. The Spacelab shall accept from the Orbiter and make audible in the Spacelab the combined Spacelab/Orbiter caution and warning and emergency tones.

7.7 RELIABILITY

7.7.1. The overall Spacelab system design and maintenance characteristics will be consistent with the design life (refer to par. 3.2). Spacelab components and subsystems shall be designed to be at least fail safe and shall be designed so as to facilitate preventive and corrective maintenance during ground operational periods. Due to potential flight repeatability, the omission of design redundancies, the utilization of non-space qualified ("CAM") equipment and/or minimized verification requirements may be considered, where it can be clearly established that (1) personnel safety will not be compromised, and (2) significant cost savings will result.

7.7.2 Failure Mode and Effect Analyses (FMEA's) which define the effect of component failures on flight objectives shall be conducted. Retention of critical failure modes will be rigorously justified, and a "Critical Item Control" programme will be established and systematically implemented for retained critical items.

7.7.3 Prior flight and/or ground tests will demonstrate, as far as possible, that system elements are capable of meeting the flight requirements. For those system elements which cannot be fully verified by prior flight and/or ground tests, engineering analyses will substantiate their capability of meeting flight objectives.

7.7.4 A Spacelab parts programme will be established and implemented, as appropriate, which controls critical parts procurement, selection, screening, evaluation, qualification, derating, failure analysis, acceptance testing, handling, storage, application reviews, and configuration control.

7.7.5 A closed loop system for failure reporting, analysis and corrective action will be established and implemented for failure occurring on critical components or systems.

7.8 QUALITY ASSURANCE

A Spacelab Quality Assurance Program will be established for controlling the following major activities:

(a) Design and development.

(b) Identification and data retrieval.

(c) Procurement.

(d) Fabrication.

(e) Inspection and testing.

(f) Nonconforming articles and materials.

(g) Metrology.

(h) Handling.

(i) Government furnished (NASA/ESA) equipment.

7.9 MATERIALS CONTROL

7.9.1 Spacelab

A materials control programme shall be established and implemented which meets the intent of reference 12.2(i). The Spacelab materials control programme will include provisions for (1) materials identification, (2) usage evaluation (including testing where warranted), (3) removing hazards, (4) processing waivers and deviations and (5) as-built controls (i.e., procedures for assuring that no materials hazards are inadvertently introduced into the Spacelab between design and mission completion). Materials to be used in the Spacelab habitable areas shall be evaluated for the Spacelab worst case environments.

The Spacelab module will provide for monitoring hazardous offgassing effects and for the removal of hazardous offgassing products.

7.9.2. Spacelab Payloads

The basic Spacelab Programme policy allows relaxed material screening requirements for payloads with respect to flammability and toxic offgassing, except for payloads to be flown in the Orbiter cabin. More stringent requirements exist for material selection for payload elements carried in the Orbiter cabin, since the Orbiter cabin must serve as the refuge in the event of emergency in the Spacelab (refer to par. 7.5.1.). Payloads flown in the Orbiter cabin will conform to Spacelab material requirements (i.e., reference 12.2(i)). Material selection requirements for payloads will be specified in reference 12.2(e).

8.0 PROGRAMME COST CONSIDERATIONS

8.1 COST

Overall programme cost will be a major consideration in all major design and operational concept decisions.

8.2 PRODUCTION AND OPERATIONAL COSTS

To enhance the utility of the Spacelab to the operator and to potential users, it is desirable that the cost of production units, including spares, and operational costs (i.e. integration, checkout, maintenance and refurbishment) be kept to a minimum.

9.0 AGENCY RESPONSIBILITIES

9.1 BASIC RESPONSIBILITIES

In accordance with reference 12.1(a), ESA is responsible for the development of the Spacelab concept agreed on jointly by NASA and ESA including flight hardware, software, and ground support equipment. ESA will direct the design, development, manufacture, qualification, acceptance test and delivery to NASA of one Spacelab flight unit, one Engineering Model, two sets of Spacelab ground support equipment, initial spares and documentation and will also provide sustaining engineering through the first two Spacelab flights. NASA will procure additional flight units, GSE, and services as required. NASA will also direct the design, development, manufacture, and qualification of the transfer tunnel. and Spacelab crew training equipment.

NASA will have primary responsibility for all operational activities subsequent to the delivery of the Spacelab, including experiment integration, crew training, checkout, flight operations, refurbishment, data acquisition, preliminary processing and distribution.

9.2 MUTUAL RESPONSIBILITIES

Because of the overlapping nature of the ESA and NASA responsibilities, certain areas require mutual involvement of the Agencies for the successful accomplishment of the programme. Specific areas identified fall into four general categories (i.e. requirements, plans, interfaces, and activities) as shown in Table 9.1.

The table also shows the Agency responsible for originating and controlling the associated documents and activities as well as the level of involvement of the other Agency in each case. The levels of involvement may change as the programme enters a new phase (e.g. during the production and procurement phase). The definitions of the levels of involvement of the "other" Agency are as follows:

A. Will review and approve the relevant activities and documents of the originating Agency and will monitor and support the originating Agency.

B. Will be given the opportunity to monitor all relevant activities (e.g. as an observer on a change board, a participant in a working group, test observer, and as an addressee for status reports, etc.) and will support the originating Agency.

C. Will support and provide relevant information to the originating Agency.

10.0 PRINCIPAL MILESTONES

The Master Working Schedule is shown in Fig. 10.1. These milestones are jointly controlled at Level I, unless otherwise noted. Additional Level I milestones are given in the list of deliverables, Table 11.1. In addition to these milestones the Heads of Agencies meet annually and the ESA/NASA Programme Directors are regularly provided access to major progress reviews of the Shuttle and Spacelab Programmes in accordance with the Memorandum of Understanding (reference 12.1(a)).

The definitions of the master milestones are as follows:

Subsystems Requirements Review (SRR)

The objective of the SRR is to update system requirements and to establish the acceptability of the contractors' subsystems level requirements baseline, and plans for implementing these requirements.

The baseline established by the SRR serves as the start for the final subsystem definitions and design phase during which detail designs will be developed, interfaces will be finalized, manufacturing drawings will be prepared and test procedures will be developed.

ESA has the responsibility for the initiation of and conduct of the SRR. NASA participates in the review of the documents and in the participation and final disposition of review item discrepancies (RID's) by means of a joint ESA/NASA Board.

Preliminary Operations Requirements Review (PORR)

The objective of the PORR is to review and baseline top level operational requirements in the areas of: flight operations, ground operations, experiment integration, logistics, data management, training, and facilities.

NASA has the primary responsibility for the initiation, conduct, and final dispositions of actions generated at the PORR. ESA participates in the PORR in a monitoring role. RID's may be generated by both NASA and ESA. Final dispositions will be made by a NASA board with ESA observers.

Preliminary Design Review (PDR)

The PDR is a formal technical review of the basic design of the complete Spacelab system to assure compatability with the previously established technical requirements baseline (including interface requirements) and the producibility of the design approach. The PDR results in the authorization to the contractor to proceed with the Engineering Model design and manufacture in accordance with the reviewed baseline.

ESA has the responsibility for the initiation and conduct of the PDR. NASA participates in the PDR in a monitoring role. RID's may be generated by both NASA and ESA. Final disposition will be made by an ESA board with NASA observers.

Operations Requirements Review (ORR)

The objective of the ORR is to review and baseline the detail operational requirements of: flight operations, ground operations, experiment integration, logistics, data management, training, facilities, developed in response to the previously baselined overall operational requirements.

The responsibilities for this review are identical with those for the PORR.

Intermediate Design Review (IDR)

The IDR is a formal technical review of the complete system including software accomplished when the detail design is essentially complete and ready for release to manufacture. It establishes compatibility of subsystem interfaces and compliance of the actual design as demonstrated by the subsystem model tests with the previously established design requirements baseline. The NASA and ESA responsibilities for the IDR are identical with those established for the PDR.

First Increment Follow-on Procurement

First increment follow-on procurement occurs with issuance of the agreement to proceed (ATP) by NASA to ESA for the procurement of flight hardware and ground support equipment required for initial operations. NASA will give an initial procurement order of at least one Spacelab at the latest two years before the delivery of the First Flight Unit.

Critical Design and Qualification Review (CDQR)

The CDQR is a formal technical review which takes place at the end of the qualification programme accomplished at the subsystem level and towards the end of the test phase of the integrated Engineering Model. It formally confirms the final production baseline of the Spacelab flight and ground support hardware and software. The purpose of the CDQR will be to determine the compliance of the complete design as demonstrated by the integrated Spacelab Engineering Model tests and its associated GSE and related analyses with performance and verification requirements and to determine that the qualification of the Spacelab system has been successfully accomplished. The NASA and ESA responsibilities for the CDQR are identical with those established for the PDR.

Second Increment Follow-on Procurement

Second increment follow-on procurement occurs with issuance of the agreement to proceed (ATP) by NASA to ESA for the procurement of flight hardware and ground support equipment required for follow-on operations.

Engineering Model Acceptance Review and Delivery

The objective of the acceptance review is to certify that the Engineering Model and GSE hardware and software offered at delivery have been developed and assembled in accordance with the released engineering documentation.

The acceptance review and the acceptance tests will be conducted with both ESA and NASA participation and will cover two acceptance procedures: the acceptance of the Engineering Model from the contractor by ESA, and its acceptance from ESA by NASA. When accepted, the Engineering Model will be ready for shipment to the U.S. A validation of the Engineering Model will take place at the destination.

The Engineering Model, one set of GSE and all necessary software, will be available in the U.S. one year prior to the delivery of the First Flight Unit for use in maintenance and refurbishment procedures development, experiment integration verification, crew training, and flight simulation, flight support trouble shooting and facility activation.

The prime responsibility for this review is assigned to ESA. NASA will participate in the review and concurs in action items generated by the review.

Final Acceptance Review (FAR) and Flight Unit Delivery

The objective of the FAR is to certify that the Flight Unit and GSE hardware and software offered at delivery have been developed and assembled in accordance with the released engineering documentation.

The acceptance review and the acceptance tests will be conducted with both ESA and NASA participation and will cover two acceptance procedures: the acceptance of the Flight Unit from the contractor by ESA, and its acceptance from ESA by NASA. When accepted, the Flight Unit will be ready for shipment to the U.S. A validation of the Flight Unit will take place at the destination.

The Flight Unit, one set of GSE and all necessary software, will be available in the U.S. one year prior to the first operational Space Shuttle flight.

The prime responsibility for this review is assigned to ESA. NASA will participate in the review and concurs in action items generated by the review.

Design Certification Review (DCR)

The objective of DCR is to certify the design of Spacelab Level III, II and I integration facilities and the design of Spacelab flight operations control for proof of design and development maturity and the design of Spacelab for flight worthiness and manned flight safety. Responsibility for the review is assigned to NASA. ESA participates as observer on the DCR board.

Flight Readiness Review (FRR)

The FRR is a consolidated review of the hardware, operational, and support elements committed to a particular mission to assess their readiness to begin the mission.

This review will be conducted at the launch site approximately one month prior to the first flight. NASA has prime responsibility for the conduct of this review. ESA will support the review.

First Two Spacelab Flights

The first two Spacelab flights have dual objectives:

- Verification of the integrated Shuttle/Spacelab system and of the services and environment provided to experiments.
- Conduct of experiments compatible with the verification mission constraints.

Verification is under the responsibility of NASA. Experiment objectives and activities on the first flight will be jointly planned and executed on a cooperative basis by ESA and NASA. ESA will provide engineering support for the first two Spacelab flights.

11.0 DELIVERABLES

The responsibilities for delivery of major end items has been specified in reference 12.1(a). Provision is also made in the same document for additional end item responsibilities by mutual agreement as programme needs dictate. Table 11.1 shows the current major ESA and NASA deliverables and the delivery dates. Delivery of each major end item will be preceeded by an acceptance review.

12.0 DOCUMENTATION

In order to assure the programme development in a manner consistent with assigned Agency responsibilities, control documentation has been identified. The principal control documents of concern to the programme heads and their relationships to each other are shown in Figure 12.1. Also shown are documents for information purposes only, the principal document in this category being the Joint Programme Plan.

The complete titles, dates of issue, and objectives of the documents are presented below. The Agency responsible for generating each document is shown in parentheses after the title.

12.1 CONTROL DOCUMENTS

(a) Memorandum of Understanding between the National Aeronautics and Space Administration and the

European Space Research Organization for a Cooperative Programme Concerning Development, Procurement and Use of a Space Laboratory in Conjunction with the Space Shuttle System, dated 14 August 73.

This document (MOU) sets forth the basic agreements between NASA and ESA on the major cooperative aspects of the Spacelab Programme. It gives the objectives and general description of the programme and assigns programme responsibilities. It describes principles of funding, NASA procurement and contingencies.

The document was jointly signed in September 1973 by the Director General of ESRO and the Administrator of NASA who are entitled to change the respective programme responsibilities by agreement. The MOU remains in force until five years after the first flight of the Spacelab, at least until 1985.

(b) Spacelab Programme Requirements Level I ESA-SL-74-1 NASA MF 74-1 Revision 2, dated September 24, 1975 (NASA)

This document (PRD) establishes the Level I programme requirements for the Spacelab Programme. It contains overall system requirements (subsystem characteristics, operational constraints, interface requirements, etc.) and major programme implementation requirements. The document is jointly signed and controlled by the NASA and ESA programme heads.

(c) Spacelab Programme Directives (NASA and/or ESA)

Direction on major activities may be issued when appropriate by the programme heads individually or jointly in the form of programme directives.

(d) Spacelab System Requirements, Level II, Issue 5, dated November 11, 1974, with subsequent change pages. ESTEC Ref. No. SLP/2100 (ESA)

This document (SRD) is derived from the Spacelab Programme Requirements Document and governs the implementation of the design and development phase of the Spacelab Programme. It represents a jointly controlled set of requirements from which further detailed system, subsystem interface and support specifications are delineated.

(e) Schedule of Deliverables, dated TBD (ESA)

This document is the official list of delivery dates for all Spacelab contract end items which are jointly controlled by NASA and ESA at Level II.

(f) Space Shuttle/Spacelab Interface Control Document, dated TBD (NASA)

This document (ICD) provides the physical, functional and procedural interfaces between the Spacelab and the Space Shuttle. Its status is maintained via existing Level II change procedures involving all affected parties, including NASA Shuttle Program Office, NASA/ESA Spacelab Programme Offices, and the major contractors.

(g) Spacelab Payload Accommodations Handbook, Level II, dated May 1975 (ESA) (Information Document until PDR)

This document (PAH) describes the main characteristics of the Spacelab system and provides information on Spacelab capabilities to enable users to determine how their payload equipment can be accommodated. Details of Spacelab/experiment interfaces and Spacelab payload support systems are provided.

(h) Integrated Logistics Requirements, dated TBD (NASA)

This document serves as the baseline for planning the Spacelab logistics efforts that are the joint responsibility of NASA and ESA. Logistics includes activities related to maintenance, spares, support documentation, transportation and handling.

(i) Product Assurance and Safety Requirements, dated TBD (ESA)

Product Assurance requirements are reflected in this document. It amplifies the product assurance requirements contained in reference 12.1(d).

(j) Qualification and Acceptance Test Requirements, dated TBD (ESA)

This document contains the requirements for the qualification of the Spacelab design and the acceptance testing of the final production hardware. It is a Level II document which is jointly controlled and from which further detailed subsystem test specifications are derived. It provides the general ground rules and plan by which Spacelab design requirements are verified.

(k) Configuration Management Plan, dated TBD (ESA)

This configuration management plan provides for all levels of management the necessary procedures and disciplines to achieve effective control over all products (documentation, hardware, software) of the Spacelab Programme.

(l) Operations Requirements Document, dated TBD (NASA)

This document describes the operations requirements, organizational structure and interfaces under which Spacelab operations will be conducted from mission assignment through post flight assessment. Operations encompass the activities required to successfully integrate payloads into Spacelab, prepare the Spacelab and its crew for flight, conduct operations in orbit and operations control on the ground, preprocess experiment data, and transport and refurbish Spacelab elements.

(m) System Specification, ERNO SY-ER-0001, dated March 21, 1975 (ESA)

This document identifies and defines the Spacelab requirements and system concept and its capabilities. In conjunction with the system support specifications, it addresses all system level requirements and characteristics and governs all lower level specifications. The document is issued by ESA and was baselined by joint Agency review actions at the PRR and SRR.

(n) Safety Critical Items List, dated TBD (ESA)

This document consists of a listing of the safety critical items in the Spacelab system. These are defined as those which affect crew safety.

12.2 OTHER DOCUMENTS

Other documents which are important references for the Spacelab Programme are listed below.

(a) NASA/ESRO Joint Programme Plan for Spacelab, dated Sep 26, 1974 (ESA)

(b) Space Shuttle Program Requirements Document, Level I, dated March 12, 1974 Rev 6. (NASA)

(c) Spacelab User's Guide, dated TBD

(d) Space Shuttle System Payload Accommodations, Level II, Program Definitions and Requirements, Vol. XIV, JSC 07700 dated July 3, 1974 with latest change pages (NASA)

(e) Safety Policy and Requirements for Payloads Using the National Space Transportation System, dated TBD (NASA)

(f) NASA/ESA Joint Spacelab User Requirement, MSFC PD 74-2 JURG NT/21, dated May 1975

(g) Natural Environment Design Requirements for the Sortie Module, TWX 64668, dated 2 June 1972 (NASA)

(h) Tracking and Data Relay Satellite System (TDRSS) User's Guide, X-805-74-176 Rev 1, dated Sep 1974 (NASA)

(i) Flammability, Odor and Offgassing Requirements and Test Procedures for Materials in Environments that Support Combustion, NHB 8060.1A, dated February 1974 (NASA)

NASA AND ESA LEVELS OF INVOLVEMENT

Key

A - Review and Approve, Monitor & Support
B - Monitor and Support
C - Provide Information and Support

* ESA or NASA as appropriate for hardware or software element being considered.

Item	Ref. Doc.	Originating and/or Controlling Agency	Other Party Involvement
I Requirements			
Programme	12.1(b)	NASA	A
Systems	12.1(d)	ESA	A
Qualification and Acceptance Test	12.1(j)	ESA	A
Verification Flight Test		NASA	A
Safety	12.1(i)	NASA	A
Operations	12.1(l)	NASA	B
Operations Design Requirements		NASA	A
II Plans			
Joint Programme	12.2(a)	ESA	A
Design and Development		* ESA/NASA	B/B
Manufacturing and Assembly		* ESA/NASA	B/B
Quality, Reliability and Safety			
Guidelines		NASA	A
Product Assurance		* ESA/NASA	A/B
Safety		* ESA/NASA	A/B
Integration and Test		* ESA/NASA	B/B
Facilities		* ESA/NASA	B/B

NASA AND ESA LEVELS OF INVOLVEMENT

Item	Ref. Doc.	Originating and/or Controlling Agency	Other Party Involvement
II Plans (cont.)			
Operations			
Mission Operations		NASA	B
Ground Operations		NASA	B
Data Management		NASA	B
Logistics Operations		NASA	B
Program Management			
Management		* ESA/NASA	B/B
Programme Control		* ESA/NASA	B/B
Schedules and Costs		* ESA/NASA	B/B
Crew Training		NASA	B
Experiment Integration		NASA	A
Logistics		NASA	A
Procurement		* ESA/NASA	B/B
Documentation		* ESA/NASA	A/B
Configuration Management	12.1 (k)	ESA	A
III Interfaces			
Shuttle		NASA	A
Experiment Requirements		* NASA/ESA	A/A
Communication Network		NASA	B
Flight Operations Control		NASA	C
Payload Operations Control		NASA	C
Refurbishment Facilities		NASA	B
U.S. Experiment Integration Facilities		NASA	B
European Experiment Integration Facilities		ESA	B
Launch Facilities		NASA	B
Payload Accommodations		ESA	A

NASA AND ESA LEVELS OF INVOLVEMENT

Item	Ref. Doc.	Originating and/or Controlling Agency	Other Party Involvement
III Interfaces (cont.)			
Ground Support Equipment (Checkout Facilities)			
Shuttle		NASA	B
Spacelab		ESA	A
Spacelab Integration Facilities		NASA	B
IV Activities			
Systems Engineering		* ESA/NASA	B/B
Design Engineering		* ESA/NASA	B/B
Development		* ESA/NASA	B/B
Configuration Control — Level I and II Dev. Hardware & Software		* ESA/NASA	A/A
Operations Planning		NASA	B
Programme Control			
Major Schedules		* ESA/NASA	A/B
Cost Related to Follow-on Production		* ESA/NASA	B/B
Program Reviews		* ESA/NASA	B/B
Documentation		* ESA/NASA	B/B
Logistics		* ESA/NASA	B/B
Product Assurance Audits		* ESA/NASA	B/B
Manufacturing		* ESA/NASA	B/B
Inspection		* ESA/NASA	B/B
Qualification Tests		ESA/NASA	B/B
Acceptance Tests beween ESA and NASA		ESA	A/A
Verification Flight Tests		NASA	B

APPENDIX

D Key Program Participants

Explanatory Note:

Attempts were made throughout the text to give credit wherever it was due. Accordingly, many important program contributors have already been identified. Invariably, however, some key participants have been overlooked or not given their just recognition. In order to compensate for those omissions, the following pages list the ESA Principals in the ESTEC team at 4 points during the development program, and some of the key leaders of four major program reviews: PRR, SRR, CDR, and DCR. My final apologies to those, who despite these efforts, are not properly recognized for their contributions to the success of Spacelab.

CHART D-1

ESTEC Spacelab Team Members
(Principals)

December 1972

Tom Curl
Frank Sperling
Andy McGrath
Ted Fokine
Roland Cosaert

May 1973

Heinz Stoewer	Study Manager
Wolfgang Nellessen	System Manager
Derek Eaton	Module Manager
Alec Kravis	Contract Officer
Gordon Bolton	Data Acquisition & Control

CHART D-1 (cont)

Joe Bruggeman	Reliability & Safety
Eckart Graf	System Analysis
Hamid Hassan	Thermal & Environmental Control
Koos Leertouwer	Integration
Pete Ley	Quality Assurance
Henry van Looij	Power
Rudi Meiner	Structures
Andy McGrath	Experiment Interfaces
Frank Sperling	System Requirements
Richard Stamm	Data Acquisition & Control
Fred Weijers	Data Acquisition & Control
Eckard Classen	Testing

January 1976

Heinz Stoewer	Project Manager
Wolfgang Nellessen	Systems Manager
Otto Steinbronn	Engineering Manager
Franco Emiliani	Operations Manager
Maurice Legg	Project Control Manager
Lars Tedemann	Product Assurance & Safety Manager
Jan Burger	Payload Advisor
Bernd Schnitzer	Contracts Officer
Charlie Cannon	Erno Resident
Robert Mory	MSFC Liaison
Frank Sperling	System Requirements
Herbert Martinides	Payload Accommodations Engineer
Rudi Meiner	System Interfaces
Ron Thory	JSC Liaison
Gordon Bolton	Avionics
Henry van Looij	Electrical Power

CHART D-1 (cont)

Reginald Prescott	Software
Hamid Hassan	Environmental Control
Alan Thirkettle	Structures
Al Thompson	Habitability
Colin Jones	Instrument Pointing System
Frank Longhurst	Operations Analysis & Integration
Ted Knudson	Ground Operations
Jochem Graf	Mission Operations
Dieter von Eckardstein	Ground Support Equipment
Eckard Classen	Integration & Testing
Dick Kolheyer	Safety
Pete Ley	Quality Assurance
Henry Wessels	Parts, Materials, & Processes

May 1983

Bob Pfeiffer	Project Manager
Frank Longhurst	Sustaining Engineering Manager
Wolfgang Nellessen	Follow-on Development/EURECA
Maurice Legg	Project Coordination
Gordon Bolton	Engineering Manager
Dieter von Eckardstein	Follow-on Procurement Manager
Lars Tedemann	Product Assurance & Safety Manager
Bernd Schnitzer	Contracts Officer
Peter Wolf	Instrument Pointing System Manager
Jeanne Slagmolen	Contracts Officer
Joechen Paque	Configuration
Rudi Meiner	Long Term Planning
Herbert Martinides	Fluid Physics Module
Michel Nerault	Mechanical
Maurice Lebreton	Thermal/Environmental Control Systems

CHART D-1 (cont)

Fred Weijers	Avionics
Helmut Heusmann	IPS (Systems Engineering)
Henry van Looij	IPS (Electrical)
Joe Bruggeman	IPS (PA/Safety)
Jochem Graf	Operations/Software
Ted Knudson	Logistics
Renato Renai	Software
Alan Thirkettle	KSC Resident Team
Henry Wessels	Product Assurance & Safety
John Bennet	Parts, Materials, & Processes
Colin Cheeseman	Quality Assurance
Keith Wright	Safety
Roy Atkins	Reliability

CHART D-2

Preliminary Requirements Review Leadership
(From October 18, 1974 Planning Package)

Review Teams

	ESRO Leader	NASA Leader
Management	H. Stoewer	--
System	F. Sperling	E. Beam
Project Control	I. Stevenson	J. Richardson
Product Assurance	L. Tedemann	R. Smith
Ground Operations	F. Emiliani	W. Taylor
Integration & Test	E. Classen	T. Dellinger

CHART D-2 (cont)

Avionics	G. Bolton	R. Tanner
Data System	G. Bolton	B. Beasley
Power	H. van Looij	R. Tanner
Mechanical	A. Thirkettle	R. Crumbley
Structures	A. Thirkettle	R. Crumbley
Payload Support	A. Thirkettle	W. Marshall
Crew	A. Thompson	R. Heckman
ECS	H. Hassan	U. Hueter
GSE	D. von Eckardstein	--
MGSE	D. von Eckardstein	A. O'Neil
EGSE	R. Selg	J. Laux
Software	R. Prescott	F. Winkler
Payload Accommodations	G. Peters	W. Marshall

NASA Preboard (at MSFC)

T.J. Lee (Chairman), MSFC
J. Kingsbury, MSFC
H. Thomasson, MSFC
O.C. Jean, MSFC
C. Brooks, MSFC
F. Kurtz, MSFC
L. Ball, MSFC
W. Brooksbank, MSFC
R. Lohman, Hdqs
R. Machell, JSC
L. Menear, JSC
R. Rose, JSC
M. Brooks, JSC
J. Dickinson, KSC
F. Bryan, KSC

CHART D-2 (cont)

A. Liccardi, Hdqs
J. Hammersmith, Hdqs
R. Sparks (Secretary), MSFC

NASA/ESRO Preboard A Prime

NASA	ESRO
L. Powell, MSFC	F. Emiliani
R. Hoodless, MSFC	W. Nellessen
J. Thomas, MSFC	O. Steinbronn
F. van Rensselaer, MSFC	L. Tedemann
C. DeSanctis, MSFC	
C. Norton, MSFC	
A. Liccardi, Hdqs	
J. O'Loughlin, JSC	
L. Menear, JSC	
R. Rose, JSC	
M. Brooks, JSC	
J. Dickinson, KSC	

NASA/ESRO Preboard A

ESRO	NASA
F. Emiliani	T.J. Lee, MSFC
W. Nellessen	J. Kingsbury, MSFC
O. Steinbronn	O.C. Jean, MSFC
L. Tedemann	R. Lohman, Hdqs
	H. Cohen, Hdqs
	G. Sharp, Hdqs

CHART D-2 (cont)

R. Machell, JSC
R. Gray, KSC
E. Kranz, JSC
Ex Officio:
D. Lord, Hdqs
P. Culbertson, Hdqs

NASA/ESRO/ERNO Preboard

Only NASA members identified -- same as for NASA/ESRO Preboard A Prime.

NASA/ESRO Board

Only NASA members identified -- same as for NASA/ESRO Preboard A.

ESRO/ERNO Board

Membership not identified.

NASA/ESRO Post-PRR Board

Only NASA members identified -- same as for NASA/ESRO Board.

CHART D-3

Subsystem Requirements Review Leadership
(From May 1, 1975 Planning Package)

Review Teams	ESA Leader	NASA Leader
Management	--	--
System	F. Sperling	E. Beam
Project Control	I. Stevenson	--
Product Assurance	L. Tedemann	C. Norton
Ground Operations	F. Emiliani	W. Taylor
Integration & Test	E. Classen	T. Dellinger
Avionics	G. Bolton	R. Tanner
Mechanical	A. Thirkettle	R. Crumbley
Environmental Control System	H. Hassan	U. Hueter
Ground Support Equipment	D. von Eckardstein	J. Laux
Software	R. Prescott	L. Grant
Payload Accommodations	G. Peters	W. Emanuel

NASA Preboard N

T.J. Lee (Chairman), MSFC
C. Hagood, MSFC
H. Thomason, MSFC
O.C. Jean, MSFC
R. Smith, MSFC
W. Brooksbank, MSFC
R. Sparks/S. Johns (Secretary), MSFC
R. Lohman, Hdqs
R. Machell, JSC
J. Dickinson, KSC
J. Hammersmith, Hdqs

CHART D-3 (cont)

ESA/NASA Preboard

NASA	ESA
L. Powell, MSFC	W. Nellessen
R. Hoodless, MSFC	R. Mory
R. Lohman, Hdqs	J. Burger
H. Cohen, Hdqs	F. Emiliani
R. Machell, JSC	M. Legg
J. Dickinson, KSC	O. Steinbronn
	I. Stevenson
	L. Tedemann

ESA/NASA Board

Only NASA members identified.

T.J. Lee, MSFC
O.C. Jean, MSFC
H. Thomason, MSFC
G. Sharp, Hdqs
H. Cohen, Hdqs
H. Gartrell, JSC
R. Gray, KSC
Ex Officio:
D. Lord, Hdqs

ESA/NASA Post SRR Board

Only NASA members identified.

T.J. Lee, MSFC
O.C. Jean, MSFC

CHART D-3 (cont)

G. Sharp, Hdqs
H. Gartrell, JSC
R. Gray, KSC

Ex Officio:
D. Lord, Hdqs

CHART D-4

Critical Design Review Leadership
(From January 10, 1978 Planning Package)

Review Teams and Subteams

	NASA Leader	ESA Leader
Design Support	R. Tanner	D. Deil
Operations	W. Taylor	--
Integration & Test	T. Dellinger	E. Classon
PA, Safety & Maintainability	J. Jarrell	R. Kolheyer/H. Wessels
Avionics	F. Applegate	G. Bolton
CDMJ	J. Atherton	F. Hardi
EPDS	J. Grubbs	H. van Looij
EGSE	J. Laux	R. Selg
Software	C. Bradford	S. Copps
Environmental Control System	U. Hueter	H. Hassan
Design & Analysis	W. Littles	P. Colson/P. Tamburini
ECS/MGSE	H. Fulmer	J. Meyer-Konig
External Contamination	C. Davis	--

CHART D-4 (cont)

Structure/Mechanics	R. Crumbley	A. Thirkettle
Structural Design	R. Griner	--
Structural Analysis	R. Hurford	M. Nerault
Dynamics Analysis	R. Schock	M. Nerault
MGSE	A. Boyanton	D. von Eckardstein
Crew Systems	R. Heckman	A. Thompson

NASA Preboard

T.J. Lee (Chairman), MSFC
L. Powell, MSFC
J. Thomas, MSFC
R. Hoodless, MSFC
A. Roth, MSFC
W. Marshall, MSFC
H. Thomason, MSFC
A. McCool, MSFC
R. Schwinghamer, MSFC
F. Moore, MSFC
J. Powell, MSFC
C. Brooks, MSFC
C. Lundquist, MSFC
E. Cagle, MSFC
R. Smith, MSFC
O.C. Jean, MSFC
W. Davidson (Secretary), MSFC
J. Kingsbury, MSFC
R. Gray, KSC
G. Lunney, JSC
C. Harlan, JSC
H. Cohen, Hdqs

CHART D-4 (cont)

J. Harrington, Hdqs
R. Lohman, Hdqs
A. Ryan, Hdqs
R. Kennedy, Hdqs
G. Esenwein, Hdqs
R. Ott, Hdqs

ESA/NASA Preboard

Only NASA members identified.

J. Thomas, MSFC
D. Germany, MSFC
R. Hoodless, MSFC
A. Roth, MSFC
C. Norton, MSFC
E. Beam, MSFC
W. Emanuel, MSFC
J. Dickinson, KSC
R. Gaskins, KSC
J. O'Loughlin, JSC
E. Thompson, JSC
R. Lohman, Hdqs
A. Ryan, Hdqs
H. Cohen, Hdqs

ESA/NASA Board

T.J. Lee, MSFC
L. Powell, MSFC
J. Thomas, MSFC

CHART D-4 (cont)

W. Emanuel, MSFC
R. Gray, KSC
I. Rigell, KSC
G. Lunney, JSC
C. Harlan, JSC
H. Cohen, Hdqs

Ex Officio:

J. Harington, Hdqs

ESA/ERNO Preboard

NASA Participants

J. Thomas, MSFC
D. Germany, MSFC
R. Hoodless, MSFC
A. Roth, MSFC
C. Norton, MSFC
E. Beam, MSFC
O.C. Jean, MSFC
J. Dickinson, KSC
R. Gaskin, KSC
J. O'Loughlin, JSC
E. Thompson, JSC

Ex Officio:

J. Harrington, Hdqs
R. Lohman, Hdqs
A. Ryan, Hdqs

CHART D-4 (cont)

ESA/ERNO Board

NASA Participants

T.J. Lee, MSFC
L. Powell, MSFC
J. Kingsbury, MSFC
O.C. Jean, MSFC
R. Gray, KSC
I. Rigell, KSC
G. Lunney, JSC
C. Harlan, JSC

Ex Officio:

D. Lord, Hdqs
J. Harrington, Hdqs
W. Schneider, Hdqs
W. Williams, Hdqs

CHART D-5

Design Certification Review Leadership

Review Teams

	NASA Team Captain	NASA Program Rep.	MDTSCO Team Leader
Electrical	E. Baggs	W. Weaver	A. Lesher
Structural/Mechanical	C. Bianca	J. Poe	J. Cheek

CHART D-5 (cont)

Command & Data Management	B. Seiler	R. Williams	K. Grounds
Software	R. Stevens	W. Lide	J. Thompson
Environmental Control	R. Humphries	A. Galzerano	R. Ferguson
Materials	F. Key	R. Beaman	P. Philyaw
Safety, Reliability & Quality Assurance	W. Jordan	L. Logan	J. Martin
Operations/Crew Systems	R. Tinius	M. Horst	W. Klus

Preboard

NASA

MSFC	JSC	KSC
J. Thompson (Chairman)	C. Harlan	W. Rock
J. Blair	J. O'Loughlin	L. Parker
G. Hopson	D. Puddy	W. Williams
R. Schwinghamer	R. Johnston	
E. Smith		
J. Sterett		
W. Taylor		
J. Walker		
F. Wojtalik		

ESA

G. Bolton
F. Longhurst
L. Tedemann

CHART D-5 (cont)

MSFC Board

W.R. Lucas (Chairman), MSFC
T.J. Lee, MSFC
C. Charlesworth, JSC
G. Page, KSC
J. Kingsbury, MSFC
W. Marshall, MSFC
R. Lindstrom, MSFC
S. Reinhartz, MSFC
R. Henritze, MSFC
C. Brooks, MSFC
B. Pfeiffer (F.A. Lonhurst), ESA

Headquarters Board

Lt. Gen. J.A. Abrahamson (Chairman), Hdqs
M. Bignier, ESA
H. Hoffmann, ERNO
J. Yardley, MDTSCO
W. Williams, Hdqs
H. Cohen, Hdqs
S. Weiss, Hdqs
W. Lucas, MSFC
G. Griffin, JSC
R. Smith, KSC
M. Weeks, Hdqs
J. Harrington, Hdqs
B. Edelson (W. Raney), Hdqs
M. Sander, Hdqs

CHART D-5 (cont)

DCR Steering Group

R. Jackson, MSFC

R. Tanner, MSFC

R. Brotherton, MDTSCO

J. James, MDTSCO

G. Bolton, ESA

F. Longhurst, ESA

L. Tedemann, ESA

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